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THE ECOLOGY OF FIVE RIVERS

by

SHIRLEY E.D. CHARLTON

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE LIMNOLOGY OF FIVE RIVERS submitted by Shirley E. D. Charlton in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Algal Ecology.

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Date: 20 December 1985

ABSTRACT

Five brown water alkaline streams located in north eastern Alberta were studied throughout 1977, 1978 and 1979. Physical and chemical factors influencing the lotic algae were examined. Various sampling techniques were compared among shallow shore, midstream riffle and shaded midstream epilithic communities. The temporal changes of species composition, cell numbers, chlorophyll a, primary productivity and nitrogen fixation were documented. Ecological factors potentially influencing epilithic algae were examined using cluster and principal components analysis.

The epilithic algae exhibited a bi-modal peak of standing crop, primary productivity and nitrogen fixation. Their spatial distribution was extremely heterogeneous and influenced particularly by physical factors such as shading and current velocity. Epilithic nitrogen fixation was found to play an important role with respect to adding new nitrogen to the lotic systems. Fixation rates were lowest in the winter period suggesting that this phenomenon is temperature related. Blue-green algae were dominant numerically among all the rivers.

Longitudinal surveys of each river provided evidence that the upper and particularly the middle reaches of these Athabasca River tributaries are the most productive. Epilithic standing crops were most diverse and highest in the middle reaches where rock substrata were most abundant. Despite the organic nature (a muskeg) of the origin of each river all systems were alkaline and predominantly influenced by groundwater ion sources during the winter period.

Discharge and related factors primarily influenced the distribution and abundance of nutrients, ions and algae.

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1.0 INTRODUCTION

Fur trader, Peter Pond, was the first white man to actually see the Athabasca Oil Sands region of northeastern Alberta in 1778 (Pratt, 1976). He was lured to the area by tales of the rich fur harvests. Then in 1882, Geological Survey of Canada mapped the region and noted the presence of naturally occurring bitumen. However, it was not until the 1920's that primitive methods were developed for extraction of the oil. By 1967 the first major commercial extraction plant began refining the oil-rich sand into synthetic crude oil.

The oil rich sands occur in the oldest cretaceous formation in the Athabasca region which is known as the McMurray formation (Smith, 1979). On both sides of the Athabasca River is an area of 194,333 hectares (121 km long and 40 km wide) from which the oil sand can be retrieved by open cast mining techniques. Consequently large tracts of land have, and will continue to be cleared of vegetation and overburden to expose the oil rich sand. It has been estimated that 26 billion barrels (1 barrel is 159.6 liters) may eventually be recovered from the region. Presently, two open cast mining developments, extract synthetic crude oil on the western shores of the Athabasca River. These are Syncrude Canada Ltd., and Suncor Canada Ltd. A third development may be created on the eastern shore of the Athabasca River in the near future.

Pratt (1976) perhaps best described oil sands development when he referred to it as "something boiling out of the imagination of some early surrealist painter with a fascination for monstrous earth moving machines and smoke belching factories...a celebration of this triumph of technology over wilderness." Indeed, there exists ample evidence already of the overwhelming impact this development will have upon the region (Smith, 1979; Fox and Ross, 1979; Walmsley and Bagg 1977; Bond and Machniak, 1977).

Prior to 1977 little ecological information concerning both terrestrial and aquatic ecosystems of the region existed. Thus the Alberta Oil Sands Environmental Research Program (A.O.S.E.R.P.) was born. The investigations reported here form a small part of this overall study and concentrate upon the benthic algae of five brown water rivers, all tributaries of the Athabasca River. From preliminary visits to the region the epilithic algal community was found to dominate in all rivers except in those upper reaches which flowed through the muskeg. It was therefore this community that was selected for study.

No generalized approaches in lotic systems have been developed. Moreover, the sampling sites were remote and only accessible by helicopter; much had to be accomplished in the field regardless of prevailing weather conditions. This investigation required both the development and testing of techniques. Equipment had to be light in weight and small because of limited space in the helicopter. Wetzel (1964) and Round and Hickman (1971) have reviewed difficulties surrounding investigations of attached algal communities. Tippett (1970), and Hansmann and Phinney (1973) used artificial substrata to quantify attached algae and found that gross underestimates of standing crops often resulted. Also, they showed that information derived using artificial substrata frequently misrepresented the natural community because colonization rates were variable, and some algal species were frequently absent perhaps because they could not adhere to the artificial substrata. Such results concur with the earlier work of Slådeckova (1962) and the more recent work of Lock and John (1980). Glass slides are frequently used in both lentic and lotic systems to assess attached algal growth but in the lotic system, in particular, they radically alter the natural flow regime. This yields a pseudo-epilithic or epiphytic community with a flora comprising species tolerant of faster current and high light levels because the glass slides are invariably suspended closer to the water surface than the natural epilithic community. Further, Butcher (1932) found reduced algal numbers on slides in faster currents while Blum (1963) showed that current affects each diatom species differently. He concluded that current acted as a governing facter in the distribution of species when artificial substrata were used. McIntire (1966) reported that faster currents in artificial streams retarded initial attachment of algae to glass slides, but after three weeks this was overcome and ultimately a greater biomass formed. Reisen _et_ _al_ (1970) found diatoms adhered best in slow currents but after six weeks diatom populations began developing at higher current velocities. They concluded that density rather than current was the prime factor affecting algal attachment. Such studies demonstrate some of the problems associated with using artificial substrata for examining attached communities.

Substrata other than glass slides have been used. Margalef (1948) employed a celluloid film which could be placed around natural substrata. Cellulose acetate strips were used by Hooper and Robinson (1978) to determine the seasonal dynamics of epiphytic algae and they reported no differences between the epiphyton on the macrophytes and the strips. Hooper's study was conducted in a quiet pond where current effects were minimal. Another problem of lotic systems involves debris carried in the water which could easily damage or sweep away any artificial substrata. To overcome the problems outlined here, any investigation of attached algal communities should be carried out using the natural substrata.Specifically examined were the epilithic algae of five rivers studying seasonal changes in species composition and numbers, standing crop, primary productivity and nitrogen fixation. The spatial distribution of algae in relation to substrata and habitat were also examined. Because nothing was known about seasonal physical and chemical fluctuations these were determined as well to allow determination of potential controlling factors in the growth and decline of the epilithic algae. The epilithic algal community displays marked spatial heterogenity; a response to differences in texture, nature and location of the substratum Douglas 1958; Round 1964; Blinn _et al_ (1980). Studies were therefore included in which various microhabitats using a variety of techniques were compared. Finally one longitudinal survey of each river was undertaken.

This thesis will provide evidence of the great dissimilarity and similarity which can be found in lotic (running water) compared to the well studied lentic (lake) ecosystems.

2.0 Methods and Materials

2.1 Water Chemistry:

Whole water samples were collected at the midstream from a depth of 30 cm below the surface in order to minimize sample contamination by floating allochthonous material. Water for metal analysis was immediately filtered through GF/A glass fibre filters to remove detritus and planktonic organisms (cf. Happy, 1970), then placed in acid washed litre bottles and returned to the laboratory where it was immediately frozen. Sodium and potassium concentrations were determined using an IL Flame Photometer, Model 148, while those of magnesium, iron, calcium and manganese were determined by atomic adsorption spectrophotometry. Dissolved silica, chloride, phosphate-phosphorous, nitrate-nitrogen, and alkalinity were determined following MacKereth (1963), and sulphate according to Anon (1976). Phosphate-phosphorus extractions using n-hexanol and ammonium molybdate were performed as soon as possible after river collection at the Mildred Lake Research Facility. Similarly, 100 mL samples utilized for nitrate-nitrogen determinations were evaporated to dryness in flat-bottomed conical flasks in the same laboratory. Subsequent analysis took place at the University of Alberta. All results were expressed as mg L^{-1}.

Specific conductance was measured with a YSI conductivity/temperature metre (Yellow Springs Instrument Co.), YSI Model 33, S-C-1 metre umhos/cm were converted to millisiemens/m; (1 mS/m = 10 umhos/cm).

2.2 Physical Factors

Temperature was measured with a mercury thermometer ($\pm$ 0.5°C accuracy). Discharge and current velocity information was supplied by Water Survey of Canada, Calgary, Alberta. Monitor stations were located very near the routine sampling stations utilized during this study.

2.3 Species Composition and Numbers

2.3.1 Epilithon

Two 4 cm^2 areas of rock were delineated by a template and the area was then scraped with a sharp scalpel to remove the epilithic algae. Separate rocks were utilized for each of the 4 cm^2 epilithon collections, then the sample pooled into sterile 30 ml vials, with 10 mls of distilled water and 10 drops of Lugol's iodine solution as preservative. Whenever possible, unpreserved samples were also examined immediately following collection to aid accurate identification of the algae.

Species composition and algal numbers were determined using the inverted microscope (Wild M-40) and sedimentation technique (Lund et al, 1958). Continuous transects were examined under 40x and 100x magnification and the algal cells identified and counted. A minimum of 200, but more frequently 300 to 2,000, algae were enumerated. To enable diatoms to be identified, subsamples were treated with a mixture of concentrated sulphuric acid, potassium dichromate, and hydrogen peroxide to remove organic matter, followed by repeated washing in distilled water to remove all traces of acid before slowly drying the cleared diatom frutules on to coverglasses and mounting in Hyrax. Algae were identified according to Bourrelly (1966, 1968, 1970), Prescott (1961), Patrick and Reimer (1966, 1975), Cleve-Euler (1951-1955) and Hustedt (1930a, 1930b, 1959, 1961-1969).

2.3.2 Epipelic Algae

During the longitudinal surveys, the upper reaches of four rivers were found to flow through Muskeg, therefore, the epipelon dominated in these regions and it too was sampled as follows. A perspex cylinder (64 cm^2 area) was inserted to a depth of 6 cm into the substrate of sediment and organic matter. The entire mud-water interface delineated by the cylinder was aspirated into a container. Upon return to the laboratory the sample was placed in a dark cool area for a period of 12 hours. Early (0600 hrs) the following morning the water phase was siphoned from the sample, and the mud-algae mixture poured into petrie dishes. Placement of lens tissue upon the mud surface facilitated entrapment of epipelic algae for enumeration and chlorophyll a analysis. This area based technique is also described by Eaton and Moss (1966), Moss (1967a, 1969) and frequently employed by Hickman (1969, 1971, 1974, 1976, 1978).

2.4 Standing Crop Measurement

Three different methods for estimating epilithic algal standing crop were evaluated during the study. They are outlined below.

2.4.1 Quadrat Technique

Two quadrats, each 400 cm^2, were selected at random and delineated by a wire mesh perimeter in each of the Muskeg River microhabitats. (Shore, less than 15 cm depth, midstream and riffle). All rocks greater than 3 cm in diameter (Douglas, 1958) were removed by hand into an enamel tray. (Figure 1) An average of 18 rocks per quadrat were then brushed with a stiff denture brush to remove all the attached community. Each rock was further washed with filtered river water to ensure complete removal of the epilithon. The total slurry volume per quadrat was determined so the slurry could be subsampled for standing crop analysis using chlorophyll a. Other subsamples were taken for species composition analysis.

Figure 1. A typical collection of rocks from a 400 cm^2 quadrat.

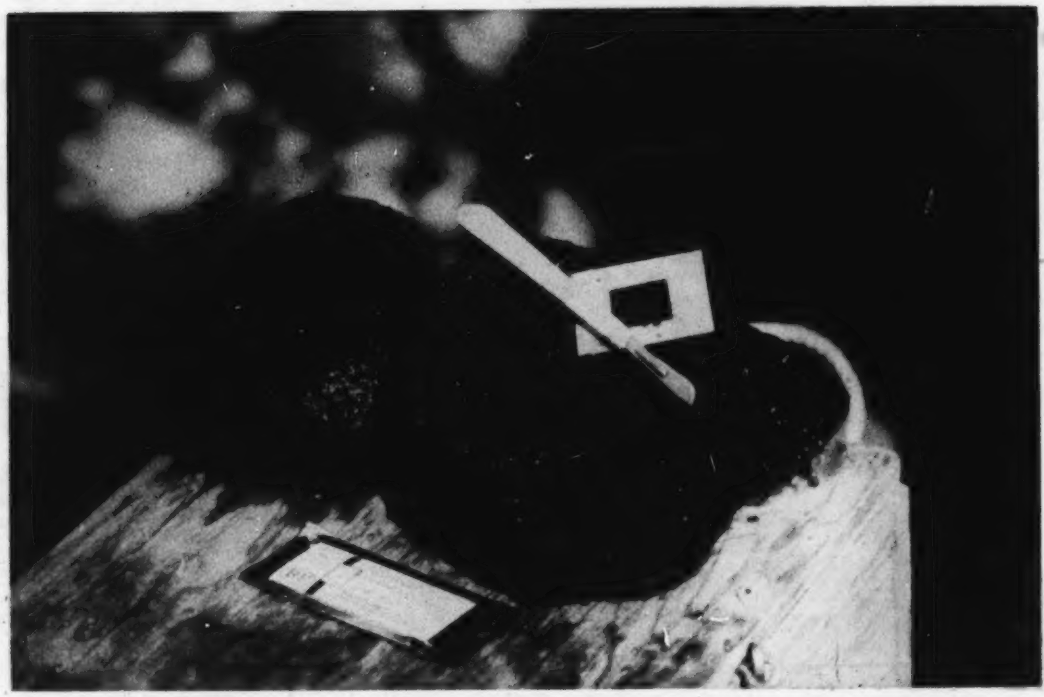


Figure 2. Photo of the template ($4cm^2$) employed for quantitative estimation of epilithic algal standing crops.

2.4.2 Scrape Technique

Paralleling the quadrat sampling technique, twelve to fifteen duplicate 4 cm^2 scrapes of the rock surface (top) were collected. The 4 cm^2 areas were delineated by means of a template (Figure 2) and the algal material scraped from the rocks to estimate the mean standing crop by chlrophyll a analysis. Thus it was possible to compare the quadrat and scraping techniques for each of the river habitats. This comparative investigation was continued for a period of one year (1977) in the Muskeg River only.

2.4.3 Brushing Technique

While the scraping technique proved to be the least cumbersome, it was not feasible to employ scraped epilithon for determination of epilithic primary productivity. Therefore, the third method employed for estimation of epilithic standing crop involved brushing individual rocks to remove all the algae associated with each rock following the ^{14}C studies. Fifteen to twenty rocks were brushed and washed, and returned to the laboratory for determination of their area planimetrically. Only the surface areas exposed to the river regime were included. A known volume (depending upon the observed population size) of epilithic slurry was subsampled for chlorophyll a analysis. The scraping and individual rock brushing techniques were compared during 1978/79 for the Muskeg River.

Three methodologies for estimating lotic epilithic algal standing crop were therefore employed throughout this comparative study. All of the epilithic slurry collected was treated similiarily, (i.e. slurry or scrape material was filtered onto Whatman GF/C glass fibre filters, covered with anhydrous magnesium carbonate, carefully wrapped in aluminum foil, and then stored at $-4^{o}C$ until the samples could be transferred to the University of Alberta, Edmonton). Storage was a necessity due to the remote nature of each sampling station. However, analysis of the filtrate followed within two weeks of sample collection. The quadrat, scrape and brush techniques were compared in a shallow near shore site (15 cm depth); midstream; artificially shaded midstream site, and riffle microhabitats of the Muskeg River(1977-1979). Artificial shading of the substrate was possible through the construction of a rectangular frame covered by two layers of nylon fly screen. (pore size 2mm). This structure reduced total incoming solar radiation by 60-80% depending upon season while yielding irregular light patterns similar to that of riparian vegetation.

2.4.4 Phytoplankton

Several authors have indicated that algae suspended in the water column of lotic systems may contribute significantly to river productivity (Patrick, 1961; Cairns et al, 1970; Swale, 1964; Whitford and Schumacher, 1963).Brown water lotic systems however have not been investigated, therefore, duplicate one litre water samples were collected from a depth of 30 cm below the midstream water surface. Whole water samples were then filtered, the filter surface covered with anhydrous magnesium carbonate, wrapped in foil and stored at -4 ° C until transported to the University of Alberta, Edmonton for chlorophyll a analysis.

Both epilithic and planktonic pigments were extracted into 90% acetone at -4 ° C for 24 hours in the dark, following homogenization using a polytron-PCU-2-110 homogenizer to ensure complete extraction. The spectrophotometric method and equations of Moss (1967a; 1967b) where correction is made for naturally occurring phaeophytin a were used.

Normality of the hydrochloric acid used during the acidification process did not exceed that recommended by Riemann (1978).

2.5 Primary Productivity

2.5.1 Epilithon

During this investigation a water powered circulating chamber was developed and employed for lotic primary production (^{14}C uptake) studies. The chamber consisted of an internal and external propellor joined by a shaft which penetrated the lid of the container. The chambers were placed into racks to allow the river currents to turn the exterior propellors throughout the four hour incubation period. Individual rocks, together with their attached epilithic algae, were carefully transferred to the glass incubation chambers. These were filled with river water and inoculated with 10 uCi $NaH^{14}CO_3$ at 1000 hours (MST). Care was taken to eliminate the air space of each jar hence the potential for 14C loss (Ilmavirta and Jones 1977; McIntire, 1966). Epilithic assays were conducted in the shore (15 cm depth), midstream and midstream artificially shaded sites of the Muskeg River. Shore and midstream habitats were assayed in the remaining four rivers. Light and dark bottles both were employed. At the end of the incubation period (1000 - 1400 hours) the epilithon were brushed from each rock. Subsamples were taken for chlorophyll a determination before the remainder of each rock slurry was preserved with buffered formalin. Each rock was labelled and retained for area determination which was accomplished planimetrically.

2.5.2 Phytoplankton

In order to define planktonic 14C uptake unfiltered river water was also incubated using light and dark incubation chambers. Assays were similarly subsampled for chlorophyll a and the remaining preserved with buffered formalin.

All formalin preserved samples of both epilithon and phytoplankton were subsampled (20 ml) and acidified to pH 2.0 with hydrochloric acid. These were then aerated for 30 minutes to remove unincorporated inorganic carbon -14 (Schlinder et al 1972). Afterwards, 2 ml subsamples were placed in Aquasol fluor and the incorporated carbon -14 determined using a Nuclear-Chicago Scintillation Computer, Model 6800. Corrections for quenching were also made.

During the diurnal investigation the same sampling methods were employed, however, a continuous series of overlapping (4 hr) incubations were conducted in-situ, commencing every two hours for a 24 hour period. ^{14}C uptake was also assayed using rocks collected along shore though midstream transects in the Steepbank, Hangingstone MacKay and Ells Rivers.

2.6 Nitrogen Fixation

2.6.1 Epilithon

Epilithic nitrogen fixation was assayed using the acetylene reduction technique (Stewart, 1968; Stewart et al, 1967, 1971). Two 4 cm^2 epilithic community scrapes were placed in 60 ml glass serum bottles along with Whatman GF/C filtered river water. The aqueous phase represented 63% of the bottle volume (Flett et al. 1975). Serum caps were fitted, 5 ml air withdrawn from each bottle and replaced with 5 ml acetylene using ethylene free disposable syringes. All bottles were then sealed with a double layer of paraffin wax, shaken for 20 seconds, to ensure that ethylene equilibrium was reached; and returned to the river for a 5 hr. in situ incubation (1000-1500 hrs. M.S.T.). The bottles were continually agitated by current in the river. Both light and dark bottles were used in addition to bottles containing only river water.

At the end of the incubation period 10 ml gas samples were removed using an ethylene free syringe, and placed in 10 ml vacutainers (Becton-Dickinson), dipped in paraffin wax and placed on ice. The remaining epilithic slurry was then field filtered onto Whatman GF/C filters covered with anhydrous $MgCO_3$, folded, wrapped in foil and also stored at -4°C. A minimum of 15 samples were assayed each time except during the diurnal study when 50 samples were assayed. Temporal studies were conducted in the shore, midstream and shaded midstream microhabitats described previously. Temporal studies in the midstream habitat were terminated when severe flooding during September, 1978, submerged the shade apparatus.

During a diurnal study five consecutive incubation series were performed over the 24 hour period on July 28, 29, 1979. In the Steepbank River, epi-bitumous and epilithic nitrogen fixation were also assayed temporally. Epilithic nitrogen fixation was assayed fortnightly in the Hangingstone, MacKay and Ells River. Samples were stored at -4°C until shipped to the University of Alberta, Department of Microbiology for further analysis. Chlorophyll _a_ content of the epilithon was determined using the methods outlined previously. Gas samples were assayed for ethylene and acetylene using a flame ionization gas chromatograph (1.5 M x 2.0 mm aluminum column, packed with Poropak R; column temperature 75 ° C, detector 125° C). Moles of ethylene evolved were converted to moles of dinitrogen fixed using the theoretical ratio of 3:1 (Hardy _et al_, 1968; Stewart, 1968).

2.7 Cluster and Principal Components Analysis

The data were examined using a multivariate analysis programme called "Clustan" (Wishart, 1973) which employed both cluster and principal component analysis (P.C.A.) Physical, chemical and biotic data for all rivers were grouped into clusters based upon similarities among sampling dates and locations. PCA was then utilized to distinguish those parameters which were most important for defining each cluster. This procedure involved calculation of a correlation matrix from which eigenvalues and eigenvectors were derived. The proportion of the total variance in the data that can be explained by each eigenvector was derived from the eigenvalue. Vectors I,II, and I,III were examined. The following standardized parameters were utilized in the cluster analysis program; ^{14}C uptake, chlorophyll a, temperature, discharge, velocity, nitrogen, P, SiO_2, pH, alkalinity, nitrogen fixation, and numbers of blue greens, diatoms and green algae. Sample dates containing missing values for any of the above parameters were excluded. A Kolmogornov-Smirnov test (SPSS) was employed to test the data distribution. Since the data were not normally distributed, values were log transformed for cluster and PCA analysis.

3. Description of the Area and Rivers

The oil sands region of northeastern Alberta is situated within the Boreal Forest (Rowe 1972). The climate is continental with significant daily as well as seasonal temperature and precipitation fluctuations. Geologically the region is underlain by Cretaceous sandstones, the oldest of which the McMurray formation comprises quartzose sands impregnated with bitumen. Devonian dolomites and gypsum occur south of Lake Athabasca while Precambrian granites occur in the extreme northeast (Carrigy and Kramers 1973). Surficial deposits comprise glacial debris. About 50 to 60% of the region possesses organic soils, and 30% aeolian sandy soils (Turchenek and Lindsay 1978).

3.1 The Muskeg River

The Muskeg River originates in the Saskatchewan Plain and flows in a southwesterly direction to its confluence with the Athabasca River (Figure 3). Draining an estimated 1092 km^2, this river flows from the Muskeg Mountain Upland (90 m elevation) and the Firebag Plain, through the Clearwater Lowlands region adjacent to the Athabasca River. (Figure 4).

The uppermost reaches of the Muskeg River range from narrow creeks barely visible in the muskeg to slow flowing pools (Figure 5). The substratum in this area is organic mud.

The slope in the uppermost reaches of the Muskeg River is 0.003. Moss, peat and sedge peat support black Spruce (*Picea mariana*), Tamarack (*Larex laricina*) and Alder (*Alnus sp.*) the predominant riparian vegetation. Submerged hydrophytes are also abundant, particularly *Myriophyllum exalbescens* and *Potamogeton spp*.

Figure 3.
Map of the study area and
major physiographic regions.

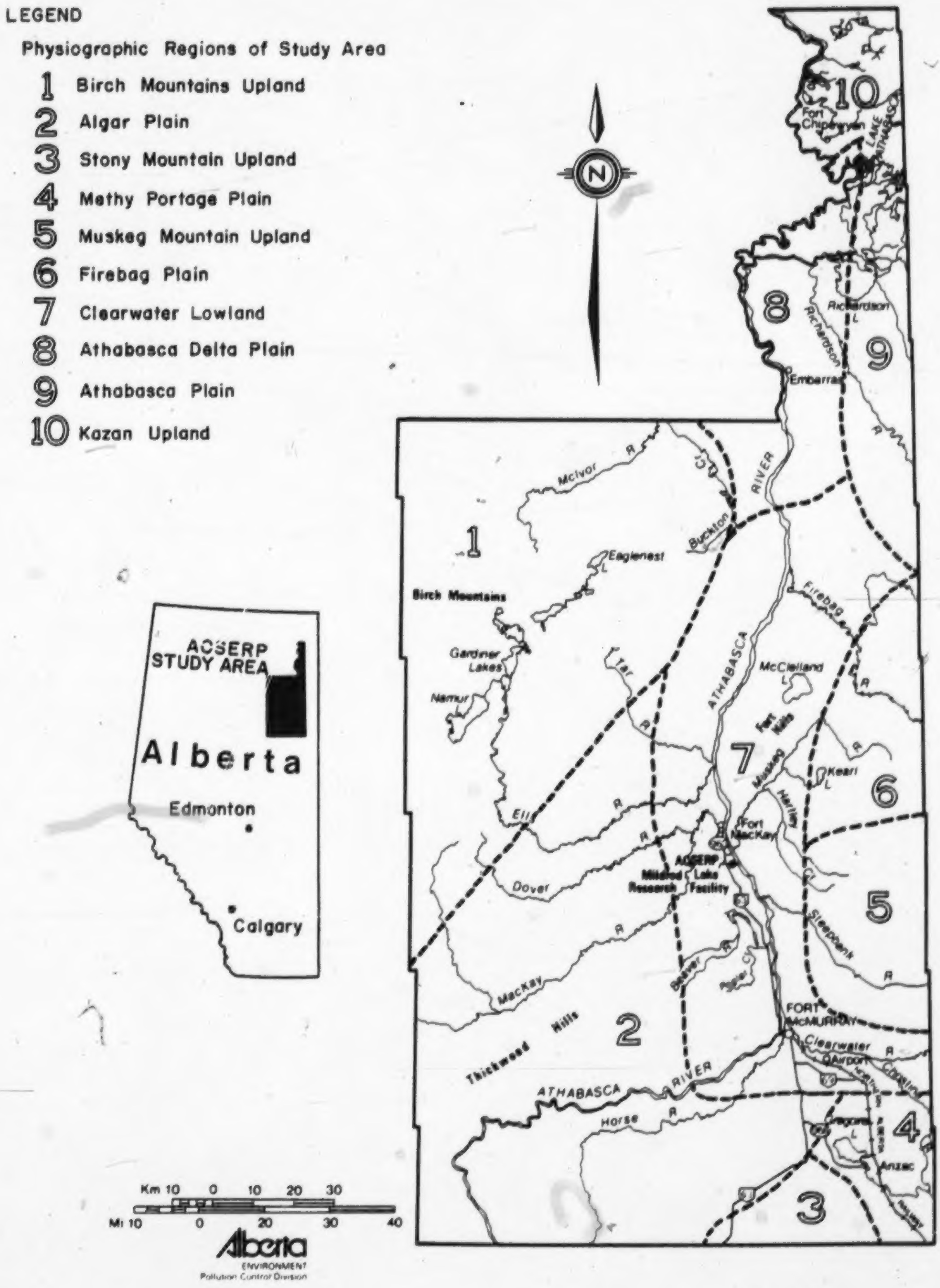
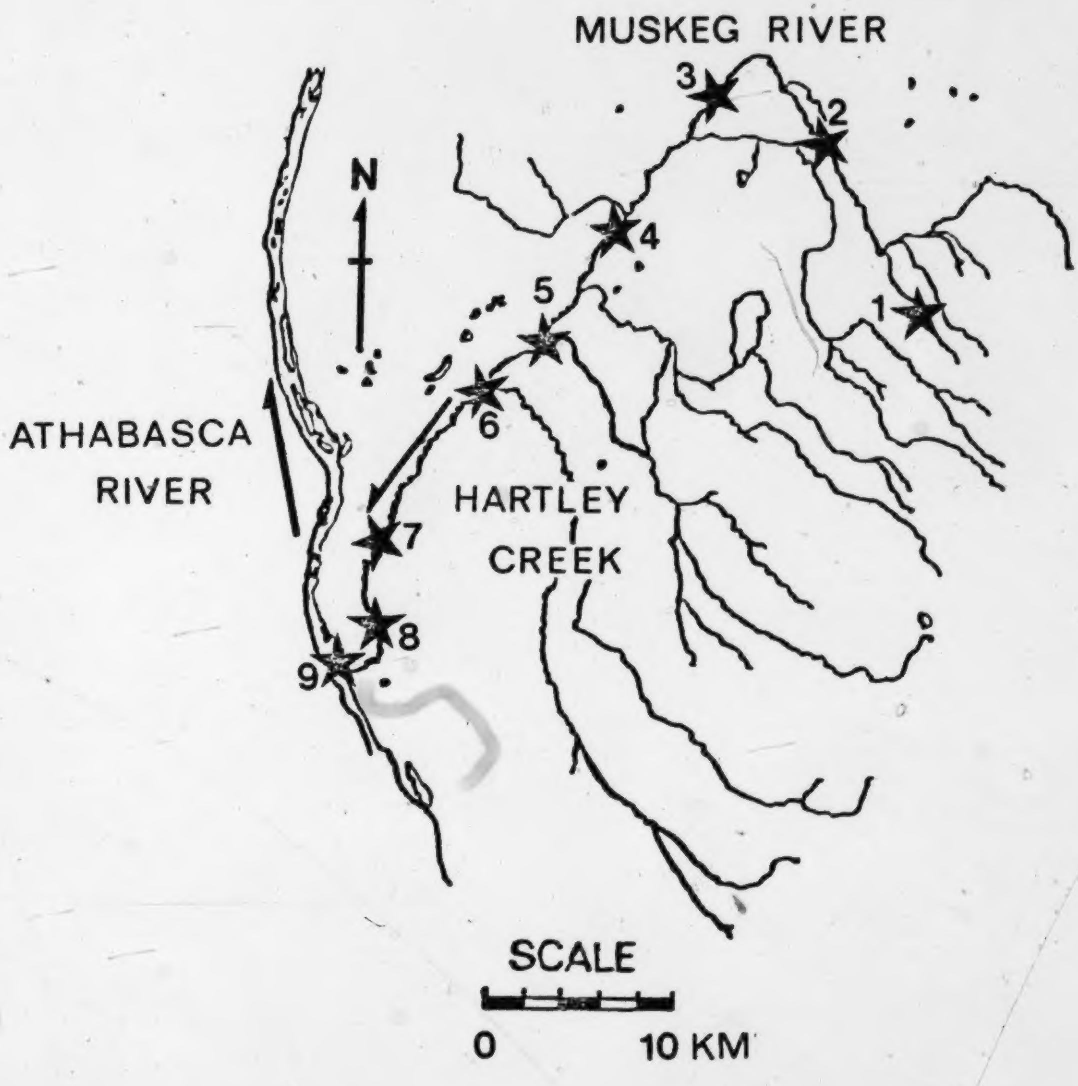

LEGEND
Physiographic Regions of Study Area
1 Birch Mountains Upland
2 Algar Plain
3 Stony Mountain Upland
4 Methy Portage Plain
5 Muskeg Mountain Upland
6 Firebag Plain
7 Clearwater Lowland
8 Athabasca Delta Plain
9 Athabasca Plain
10 Kazan Upland
N
AOSERP STUDY AREA
Alberta
Edmonton
Calgary
Fort Chipewyan
LAKE ATHABASCA
Richardson
Richardson L
Embarras
McIvor R
Birch Mountains
Eaglenest L
Buckton
Gardiner Lakes
Namur L
RIVER
ATHABASCA
Firebag
McClelland L
Fort Hills
Kearl L
Muskeg
Fort MacKay
AOSERP Mildred Lake Research Facility
Ells R
Dover
MacKay
Beaver
Steepbank
Thickwood Hills
FORT McMURRAY
Clearwater R
Airport
Christina
ATHABASCA RIVER
Horse R
Gregoire L
Anzac
Km 10 0 10 20 30
Mi 10 0 20 30 40
Alberta ENVIRONMENT Pollution Control Division

Figure 4.
Map of the Muskeg River showing positions of the sampling sites.


MUSKEG RIVER
N
ATHABASCA
RIVER
HARTLEY
CREEK
1
2
3
4
5
6
7
8
9
SCALE
0
10 KM

Throughout the upper and middle reaches of the Muskeg River the riparian vegetation remains similar, frequently shading the shores. Angular limestone and cobble substrates become increasingly abundant throughout the middle reaches of pools and riffles. The lower reach of the Muskeg River unlike any other region of the river, is steep-sided, supporting Black Spruce (*Picea mariana*). Tamarack (*Larix larisicina*), Jack Pine (*Pinus banksiana*), and Alder (*Alnus sp.*) (Figure 6).

The substratum is predominatly limestone, with swiftly flowing shallow waters. A longitudinal survey of this river indicated that while its width is variable, it rarely exceeds 8 meters. The following table indicates the specific locations and characteristics of each site sampled during the longitudinal helicopter survey of 1979.

The physical-chemical characteristics of the Muskeg River are presented in Table 2.

Figure 5. The Muskeg River, uppermost reach.

Figure 6. The Muskeg River lower reach, immediately upstream from its confluence with the Athabasca River.

Table 1: The latitude and longitude, and a brief site description for the Muskeg river.

Site	Latitude	Longitude	Brief Description
1	57° 17'N	111° 04'W	Located on a headwater stream meandering through muskeg, sub stratum-organic mud; submerged hydrophytes (Myriophyllum exalbescens, Potamogeton spp.) present.
2	57° 21'N	111° 08'N	Substratum-organic mud; mats of Spirogyra sp. plus submerged hydrophytes (Potamogeton spp., and Utricularia vulgaris). Flows through Muskeg.
3	57° 22'N	111° 14'W	Substratum-organic mud; no substantial hydrophytes; surrounded by muskeg.
4	57° 16'N	111° 21'W	Substratum-cobble (10-40 cm diameter); shaded by overhanging trees.
5	57° 15'N	111° 25'W	Substratum-sand to angular limestone rocks; both pool and riffle areas present.
6	57° 9'N	111° 30'W	Riffle predominant; substratum-flat limestone rocks (4-10 cm diameter) river valley steep sided.
7	57° 7'N	111° 33'W	As Above
8	57° 8'N	111° 38'W	As Above
9	57° 7.5'N	111° 36'W	Situated near confluence of the Muskeg and Athabasca Rivers; substratum-silt.

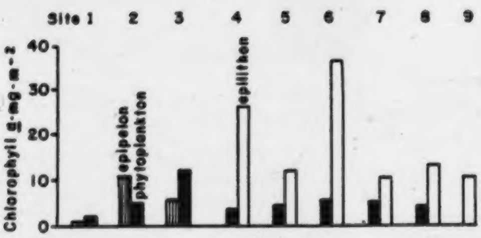
Table 2: Physical-chemical conditions at each site in the Muskeg River during July 1978.

	Sites								
	1	2	3	4	5	6	7	8	9
Depth (cm)	40	105	175	40	40	50	50	40	120
Width (m)	0.8	4.0	3.0	4.0	8.0	6.0	5.0	4.0	7.0
Temperature (^{o}C)	16	22	22	23	23	24	24	24	24
pH	7.0	7.2	7.3	7.5	7.8	7.9	8.1	8.0	8.0
Alkalinity (meqL^{-1})	4.62	3.35	3.65	3.15	2.22	2.32	3.25	3.20	3.20
Conductance (mS/m)	31.2	24.0	25.5	25.5	31.0	32.5	29.6	35.5	38.0
Magnesium (mg L^{-1})	22.1	17.0	18.3	11.8	10.9	10.9	10.3	11.5	11.9
Calcium (mg L^{-1})	33.3	26.1	30.9	31.5	25.8	32.7	26.9	35.7	38.6
Sodium (mg L^{-1})	6.5	5.2	5.6	12.4	33.5	33.5	31.5	35.2	34.8
Potassium (mg L^{-1})	0.30	0.50	0.50	0.60	0.97	0.70	0.50	0.50	1.10
Iron (mg L^{-1})	0.03	0.08	0.104	0.179	0.166	0.148	0.119	0.148	0.135
Manganese (mg L^{-1})	0.030	0.009	0.012	0.002	0.002	0.002	0.005	0.002	0.009
Chloride (mg L^{-1})	0.5	0	0	0	21.5	20.5	19.5	23.5	23.0
Sulphate (mg L^{-1})	0	0	0	0	0	0	3.5	4.5	4.4
Phosphate (mg L^{-1})	0.028	0.032	0.039	0	0	0.011	0.019	0.019	0.024
Nitrate (mg L^{-1})	0.083	0.143	0.150	0.150	0.126	0.130	0.132	0.138	0.135
Silica (mg L^{-1})	7.20	5.80	5.70	5.25	4.30	4.20	4.25	4.00	4.97

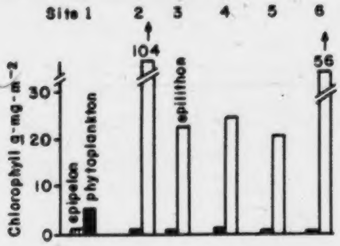
Temperature was coolest in the headwaters and thereafter remained relatively constant. pH rose in a downstream direction being lowest at sites 1 to 3 where it flowed through Muskeg. It rose at site 4 where it then began flowing over limestone. Chloride levels were undetectable at sites 2 through 4 but dramatically increased at site 5 remaining high afterwards. Sulphate displayed a similar trend but did not become detectable until Site 7. Its increase was not as dramatic as chloride. Specific conductance varied little from site to site ranging from 24.0 to 38.0 mS/m at sites 2 and 9 respectively. Calcium levels fluctuated little and irregularly whereas those of magnesium were initially high but decreased after site 3 to remain quite constant. In contrast, sodium concentrations were low until site 4 but by site 5 a sixfold increase had occurred. From site 5 to 9 levels remained constant. Of the major cations, potassium concentrations were lowest and fluctuated least.Nitrate concentrations were initially low but by site 2 they had nearly doubled. Afterwards, they remained high fluctuating irregularly. Phosphate levels varied even more. High values occurred at sites 1 through 3, but it was undetectable at sites 4 and 5; afterwards a downstream increase occurred. Silica concentrations were again highest in the upper reaches gradually falling from site 1 to 4. Thereafter they changed little.

Phytoplankton standing crops were relatively small on an areal basis ranging from 2.5 to 12.5 mg m^{-2} chlorophyll at sites 1 and 3 respectively (Fig. 7). After site 3 values fell and remained fairly constant ranging from 4.0 to 6.0 mg m^{-2}. The epipelon alone was the benthic algal community at sites 1 through 3 with the largest standing crop (10.7 mg m^{-2} chlorophyll occurring at site 2 (Fig. 7).

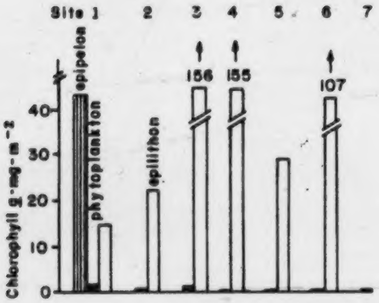
Figure 7.
Algal standing crops at each
site for the five rivers.



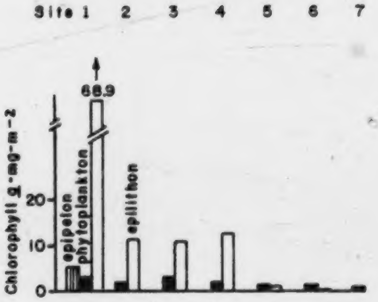
Muskeg River



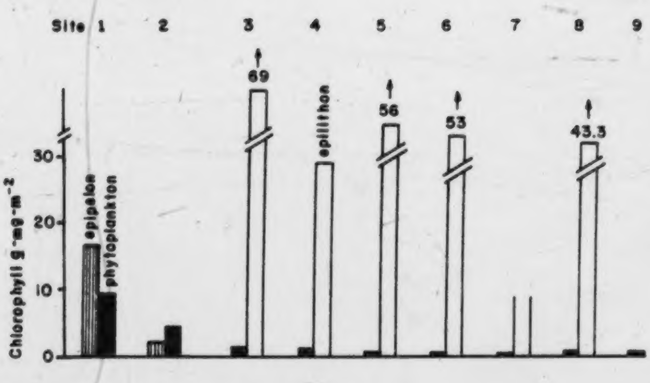
Steepbank River



Hangingstone River



Ells River



MacKay River

The epilithon dominated from site 4 onwards with sites 4 and 6 possessing the largest standing crops (26.2 and 36.7 mg chlorophyll a m^{-2} respectively).

The algae found at each site are presented in Appendix I. Only Lyngbya aerugineo-caerulea was found at all sites, being most abundant at all but sites 2 and 3 ranging from 34.5 to 96.2% of the total community (Table 3). Calothrix braunii and Cladophora glomerata were confined to sites 4 through 8 inclusive with the former producing a significant population at sites 5, 6, and 8, and the latter at sites 4, 6 and 7 (Table 3). Chlamydomonas spp. and Eunotia lunaris were confined to sites 1 through 3 but both were important in this region. Of the other algae forming significant populations, Tabellaria fenestrata was confined to sites 1 and 2, Merismopedia glauca and Gomphosphaeria lacustris v. compacta were confined to site 2 while Fragilaria capucina, and Anabaena affinis were confined to sites 2, 6 and 7 and 2,3 and 6 respectively, and Stigeoclonium sp. occurred at sites 5 and 8. In contrast, the diatoms Navicula cryptocephala, Fragilaria vaucheriae, and Cocconeis placentula were more widely distributed while other algae were more limited and showed variable occurrences (Table 3).

Routine investigations of the seasonal dynamics of physical-chemical and biotic elements were conducted at 111° 34' 25" W long, 57° 11' 30" N lat. (Figure 8, 9). This site (accessible initially by road and later by helicopter) was diverse, providing pool, riffle, shore and shaded habitats. Due to its proximity to the Mildred Lake facility it was also possible to transport the materials necessary for ongoing shaded habitat studies to the site. This site was utilized by other members of the A.O.E.S.R.P. aquatic fauna research team.

Table 3. The dominant algal species found at each site in the Muskeg River.

Site	Species	Percentage of Total Community (%)
1	*Lyngbya aerugineo-caerulea*	34.5
	Chlamydomonas	20.6
	Tabellaria fenestrata	6.9
	Eunotia lunaris	5.2
2	*Gomphosphaeria lacustris* v. *compacta*	19.2
	Lyngbya aerugineo-caerulea	18.0
	Fragilaria capucina	12.5
	Merismopedia glauca	12.0
	Fragilaria vaucheriae	9.6
3	*Oscillatoria* sp.	42.5
	Chlamydomonas spp.	14.2
	Lyngbya aerugineo-caerulea	7.1
	Anabaena affinis	5.6
	Navicula cryptocephala	4.3
4	*Lyngbya aerugineo-caerulea*	58.9
	Cladophora glomerata	41.1
5	*Lyngbya aerugineo-caerulea*	96.2
	Calothrix braunii	2.7
6	*Lyngbya aerugineo-caerulea*	82.4
	Anabaena affinis	5.1
	Cladophora glomerata	4.3
	Calothrix braunii	3.4
7	*Lyngbya aerugineo-caerulea*	85.5
	Cladophora glomerata	12.1
8	*Lyngbya aerugineo-caerulea*	59.4
	Calothrix braunii	24.6
	Stigeoclonium sp.	5.9
	Cocconeis placentula	3.3

Figure 8. The Muskeg River, routine sampling site.

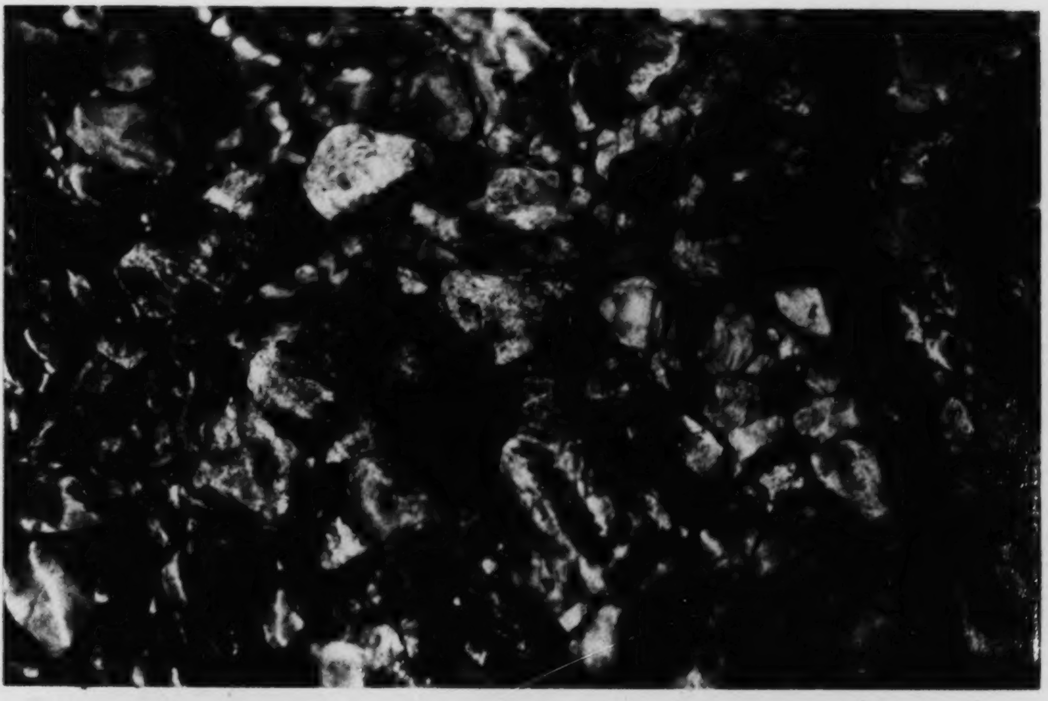


Figure 9. Routine sampling site substrate (July, 1978) and epilithic macroalgae.

3.2 The Steepbank River

The Steepbank River drains 1425 km^2 of outwash sands and gravels derived from glacial drift and muskeg. Flowing in a west-south westerly direction, it originates in the Muskeg Mountain Uplands of the Saskatchewan Plain and crosses the Clearwater Lowlands adjacent to the Athabasca River (Figure 3). The locations and specific description of each site examined during the 1979 longitudinal survey appear in Figure 10 and Table 4.

The uppermost reach of the Steepbank River consists of slow flowing pools over an organic substrate (Figure 11). Throughout the middle reaches both organic and cobble substrates can be found, frequently shaded by overhanging vegetation (Figure 12). The lower reaches of the Steepbank River, particularly downstream of the Steepbank and North Steepbank confluence, are bounded by oil-rich cliffs of sand and cobble. Larger spruce and poplar species along the banks in the lower reaches are subject to loss into the river due to bank erosion. Immediately upstream of the Steepbank confluence with the Athabasca River, the substrate is again organic silty/mud rich in oil sand. During periods of high flow in the Athabasca River the Steepbank River frequently backs up, forming pools for 0.5 km upstream from the mouth.

The physical-chemical characteristics of the Steepbank River are presented in the following Table 5.

Figure 10.
Map of the Steepbank River showing positions of the sampling sites.

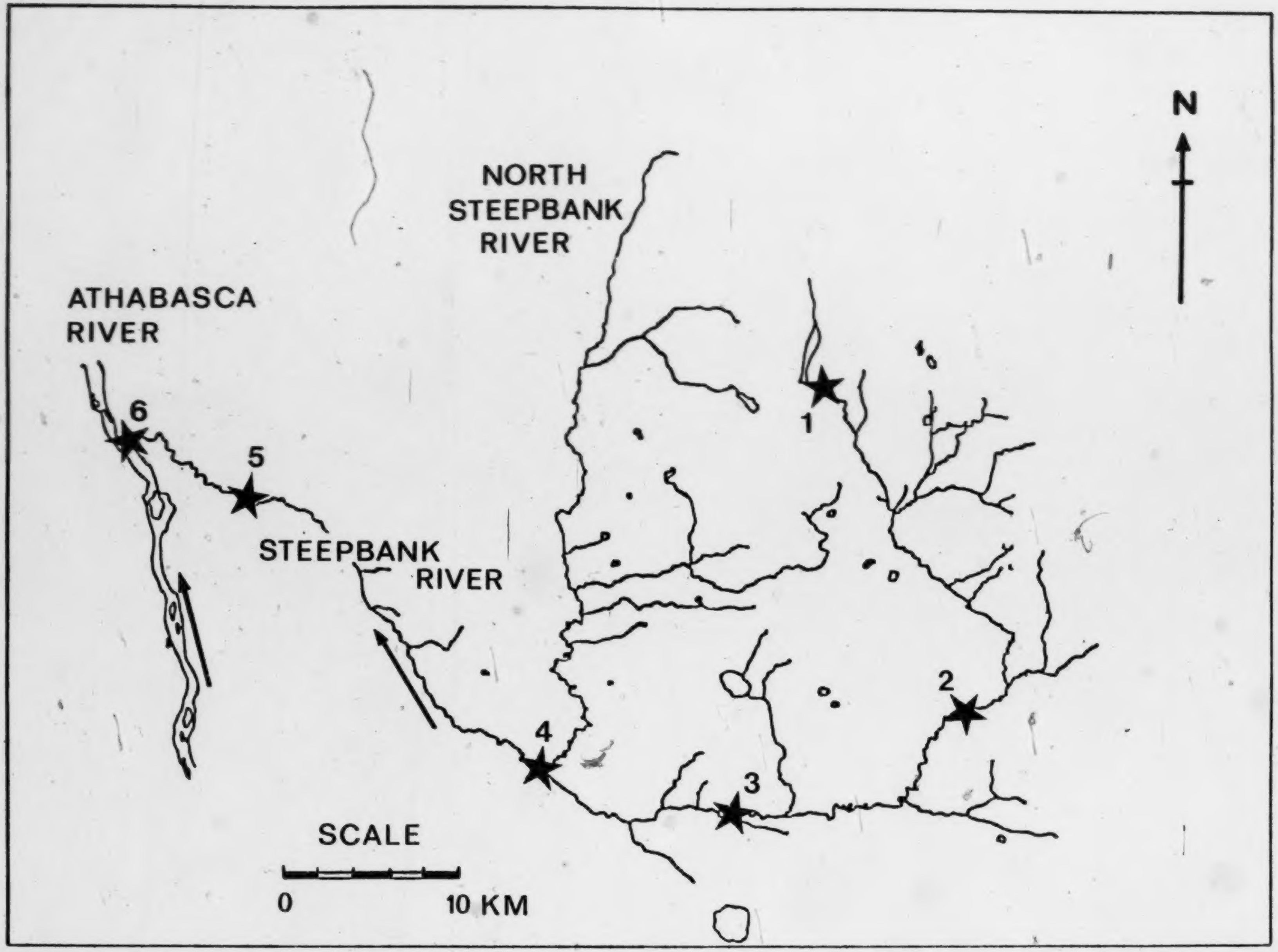

N
NORTH STEEPBANK RIVER
ATHABASCA RIVER
STEEPBANK RIVER
1
2
3
4
5
6
SCALE
0
10 KM

Figure 11. Uppermost reach of the Steepbank River.

Figure 12. Middle reach of the Steepbank River immediately downstream of the Steepbank and North Steepbank confluence.

Table 4: The latitude, longitude and brief description of each sampling site in the Steepbank River

Site	Latitude	Longitude	Brief Description
1	57° 3'N	110° 50'W	Situated on a small headwater stream flowing through muskeg; numerous slow flowing pools present; substratum-organic mud.
2	56° 53'N	110° 40'W	Similar to site 1 but river banks much steeper (0.5 to 2 m high); substratum-organic/sandy mud.
3	56° 50'N	110° 54'W	Riffle region; swiftly flowing water; substratum-cobble (5 to 80 cm in diameter); shaded by overhanging trees. River banks 2 to 3 m high.
4	56° 5'N	111° 06'W	At confluence of Steepbank and North Steepbank rivers (Fig. 5); substrata - large stones and flat limestone rocks (5 to 40 cm diameter).
5	56° 50'N	111° 21'W	Bounded by steep banks rich in oil sand; slow flowing plus riffle regions, substratum-cobble, granite and oil sand. Extensive wear of "pavement-like" oil sand along shoreline.
6	57° 01'N	111° 28'W	Confluence of Steepbank and Athabasca rivers; substratum - silty/mud rich in oil sand.

Table 5. The physical-chemical characteristics of the Steepbank River during July, 1978.

	Sites					
	1	2	3	4	5	6
Depth (cm)	50	70	35	40	45	80
Width (m)	1.5	3.0	6.0	7.0	8.0	6.0
Temperature (^{o}C)	10.6	10.4	9.0	9.2	9.2	9.2
pH	7.2	7.0	7.1	7.3	7.4	7.3
Alkalinity (meq L^{-1})	1.46	1.91	2.10	2.18	2.35	1.78
Conductance (mS/m)	13.6	18.0	19.5	15.5	20.5	20.5
Magnesium (mg L^{-1})	5.5	8.0	8.6	7.9	9.2	8.6
Calcium (mg L^{-1})	15.7	20.1	22.1	19.5	23.1	21.6
Sodium (mg L^{-1})	7.5	8.8	13.2	12.0	14.4	14.5
Potassium (mg L^{-1})	0	0.4	0.5	0.6	0.5	0.5
Iron (mg L^{-1})	0.11	0.30	0.13	0.12	0.14	0.14
Manganese (mg L^{-1})	0.002	0.002	0.017	0.002	0.013	0.004
Chloride (mg L^{-1})	2.5	0	0	0	0	0.5
Sulphate (mg L^{-1})	1.15	0	0	0	7.75	4.75
Phosphate (mg L^{-1})	0.018	0.048	0.071	0.053	0.043	0.220
Nitrate (mg L^{-1})	0.211	0.224	0.212	0.213	0.209	0.217
Silica (mg L^{-1})	3.4	3.7	3.1	3.4	2.8	2.6

The river, although shallow, was deeper in the upper reaches than downstream mainly due to the narrowness of the river and steep shore. Beyond site 2 river width rapidly increased from 3 to 6 m, and the river valley itself became wider.

Little change in both temperature and pH occurred even though, particularly with respect to pH, the headwaters regions flowed through muskeg areas (Table 5). Alkalinity on the other hand, generally increased in a downstream direction; again the range was small. Conductance was initially low at site 1 but increased afterwards and thereafter fluctuated little except at the confluence of the North Steepbank and Steepbank rivers (site 4). Here it decreased. Magnesium and sodium levels were initially low (site 1), increased at site 2 and thereafter remained very similar. Calcium values also changed little although they were slightly lower at site 1. Potassium levels were lowest and undetectable at site 1. They fluctuated least. Both chloride and sulphate were undetectable at several stations. Detectable levels were low. Both iron and manganese also fluctuated little. All the major nutrients were detectable at all sites. Nitrate and silica concentrations were most stable while phosphate values displayed a far greater range but no definite downstream trend.

Phytoplankton standing crops were highest (5.5 mg m^{-2} chlorophyll) at site 1. Afterwards they were small and changed little. At site 1 also the epipelon dominated but the standing crop was tiny (0.76 mg m^{-2} chlorophyll. By site 2 the epilithon dominated with a standing crop of 104 mg m^{-2} chlorophyll. It was lower at sites 3, 4, and 5 but increased again at site 6 (Fig. 7).

Table 6. The dominant algal species found at each site in the Steepbank River.

Site	Species	Percentage of Total Community (%)
1	*Anabaena affinis*	67.7
	Nostoc spp.	31.2
2	*Lyngbya aerugineo-caerulea*	53.2
	Batrachospermum vagum	38.8
3	*Lyngbya aerugineo-caerulea*	53.4
	Cladophora glomerata	16.4
	Cocconeis placentula	11.5
	Microspora Loefgrenii	5.6
	Anabaena affinis	4.5
4	*Calothrix braunii*	48.6
	Anabaena affinis	34.9
	Lyngbya aerugineo-caerulea	11.6
5	*Cocconeis placentula*	37.0
	Epithemia sorex	17.6
	Lyngbya aerugineo-caerulea	7.8
	Synedra ulna	7.0

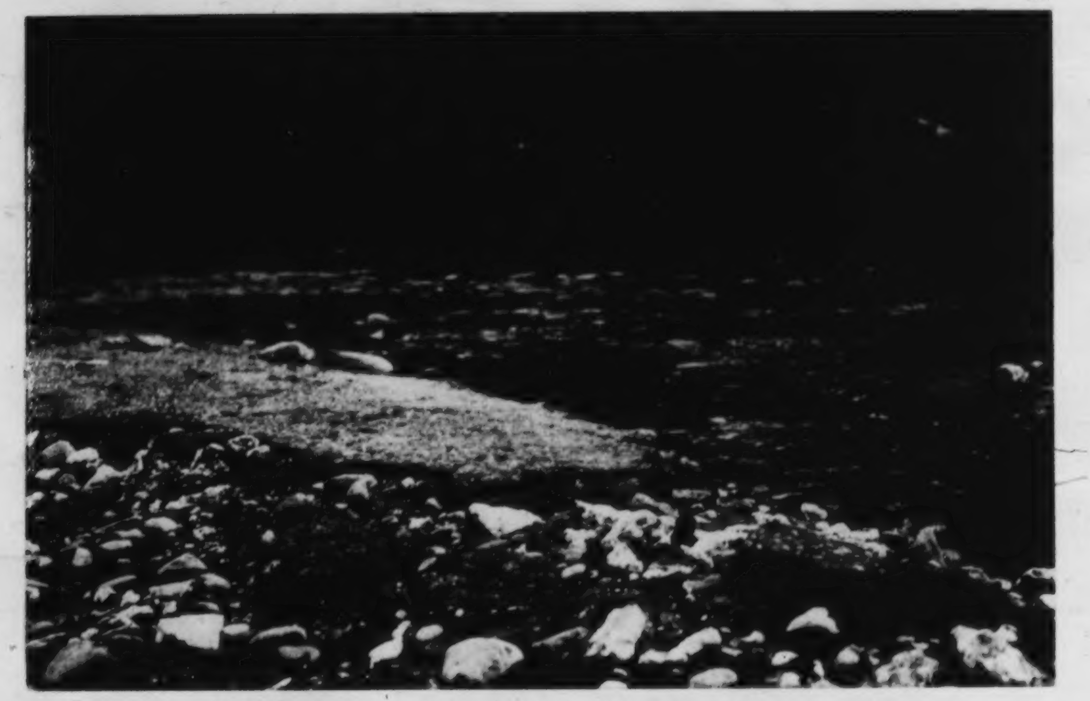


Figure 13. Steepbank River substratum of cobble and oilsand at the routine sampling site.

Figure 14. Steepbank River routine sampling site immediately upstream from its confluence with the Athabasca River.

The algae found at each site are presented in Appendix 2. No one species was found at all sites. *Lyngbya aerungineo-caerulea*, *Nostoc* spp., *Cocconeis pediculus*, *Cyclotella meneghiniana*, *Navicula cryptocephala*, *Rhopadolia gibba* and *Synedra ulna* occurred at all but one site. Of these *Nostoc* spp., *Lyngbya aerugineo-caerule-a* and *Cocconeis placentula* were dominant at several sites (Table 6). *Batrachospermum vagum* was only found at site 2 but here it comprised 38.80% of the total community. Five other species *Anabaena affinis*, *Cladophora glomerata*, *Microspora Loefgrenii*, *Calothrix braunii* and *Epithemia sorex* were important at one site at least. (Table 6). Other species were present in small numbers but with variable downstream occurrences. Diatoms such as *Cocconeis pediculus*, *Cyclotella meneghiniana*, *Navicula cryptocephala*, *Rhopalodia gibba*, and *Synedra ulna* were consistently found in small numbers.

Routine investigations were conducted at 111° 28' 50" W long, and 50° 01' 15" N lat., where submerged sandstone, granite and oilsand substrates were available for investigation. This site is also immediately east of the present Suncore Ltd. mining activity, and subject to imminent destruction in light of the abundance of oilsand with as little as 0.5 m of overburden (Figure 13,14).

3.3 The Hangingstone River

The Hangingstone River drains a smaller area (914 km^2) and again muskeg dominates in the upper reaches (Figure 16,17), but the riverbed quickly changes from organic mud to rocks and gravels. It meanders across the Algar Plain and Methy Portage Plain of Lower Cretaceous shales and sandstones and throughout the Clearwater Lowlands, emptying into the Athabasca River, west of Fort McMurray (Figure 3).

Figure 15.
Map of the Hangingstone River showing
positions of the sampling sites.

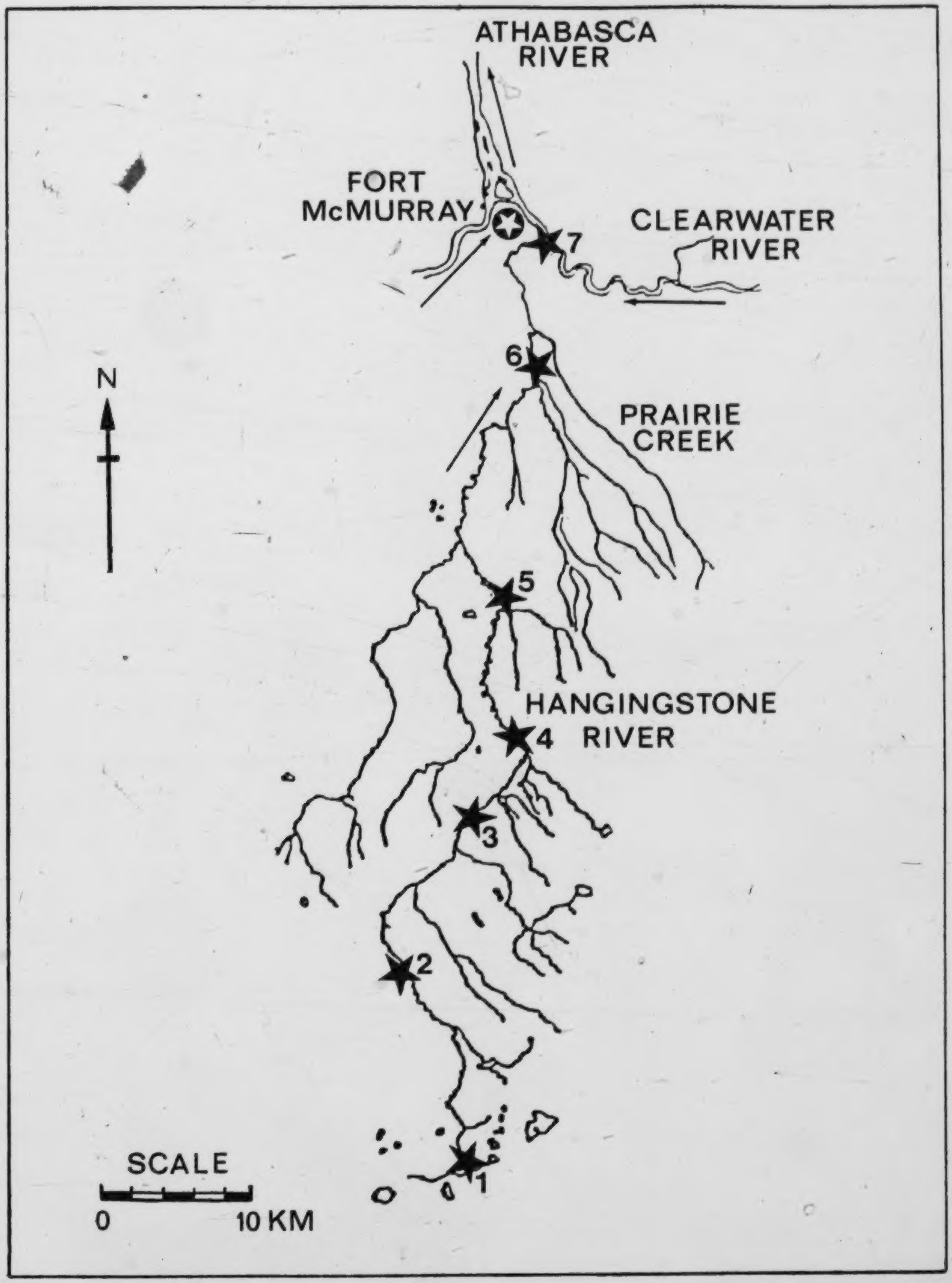

ATHABASCA RIVER
FORT McMURRAY
CLEARWATER RIVER
7
6
PRAIRIE CREEK
N
5
HANGINGSTONE RIVER
4
3
2
1
SCALE
0
10 KM

Figure 16. Uppermost reach of the Hangingstone River in the Stony Mountains Uplands.

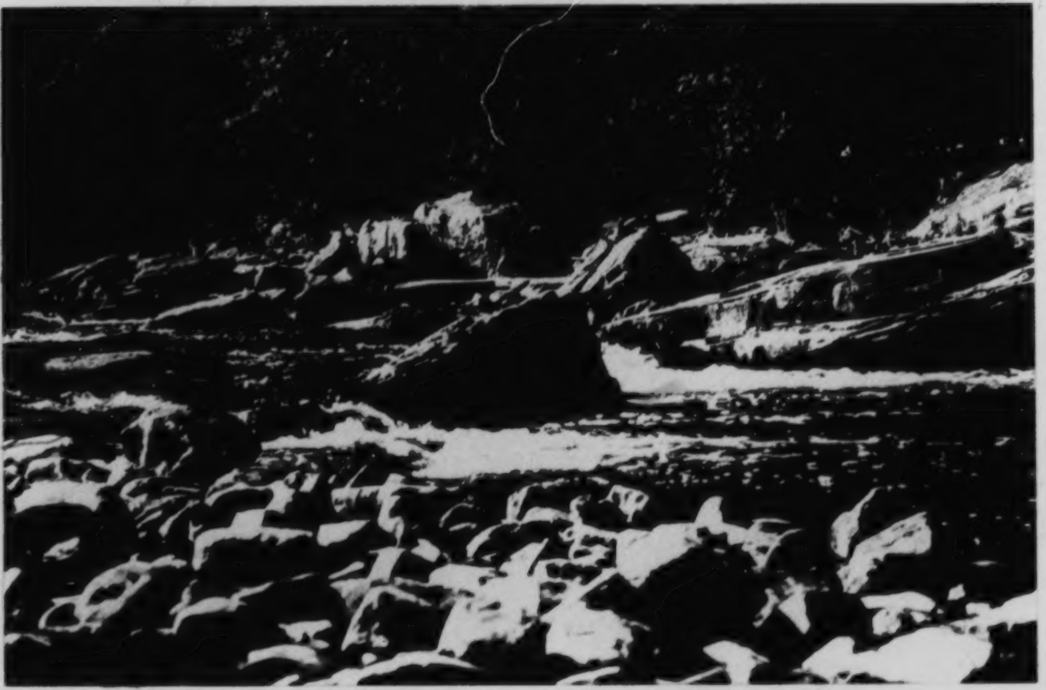


Figure 17. Hangingstone River routine sampling site.

This river flows through the town of Fort McMurray and can be expected to be influenced by the population and local industry. Figure 15 and table 7 depict the specific location and description of each site examined during the 1979 longitudinal survey.

Table 7: The latitude, longitude, and brief description of each site in the Hangingstone River.

Site	Latitude	Longitude	Brief Description
1	56° 15'N	111° 28'W	Situated on a slow flowing, headwater stream meandering through muskeg various submerged hydrophytes present (Hippurus spp.) dominant; substratum organic mud.
2	56° 18'N	111° 31'W	Water swiftly flowing over cobble (6 to 30 cm diameter). Shaded by overhanging trees.
3	56° 23'N	111° 26'W	River banks nearly vertical, 15 m high; substratum-cobble (6 to 40 cm in diameter).
4	56° 25'N	111° 23'W	Swiftly flowing water. Substratum sand, cobble (5 to 35 cm diameter and some exposed oil sand.
5	56° 30'N	111° 24'W	Swiftly flowing water, substratum-cobble (6 to 40 cm diameter).
6	56° 37'N	111° 22'W	Situated immediately upstream of Fort McMurray. Riffle area; swiftly flowing water; substratum cobbled plus flat sandstone rocks (6 to 50 cm diameter).
7	56° 37'N	111° 20'W	At confluence of Hangingstone and Clearwater rivers (Fig. 15). Substratum-sand and cobble.

Table 8: Physico-chemical conditions at each site in the Hangingstone River during July, 1978

	Sites						
	1	2	3	4	5	6	7
Depth (cm)	50	30	50	40	50	45	60
Width (m)	2.0	3.0	3.0	8.0	10.0	8.0	10.0
Temperature (^{o}C)	8.8	7.5	8.2	7.5	9.2	10.5	10.9
pH	6.1	6.9	7.2	7.4	7.4	7.5	7.8
Alkalinity (meq L^{-1})	0.70	1.95	2.00	2.16	2.16	1.95	2.00
Conductance (mS/m)	50.0	16.5	23.0	20.5	21.5	22.0	24.0
Magnesium (mg L^{-1})	1.8	7.2	8.8	8.2	8.6	8.2	8.4
Calcium (mg L^{-1})	7.2	18.0	27.3	21.9	23.1	22.2	22.0
Sodium (mg L^{-1})	0.6	5.5	10.0	10.5	11.6	15.2	21.3
Potassium (mg L^{-1})	0.03	1.1	1.4	1.4	¼1.7	1.1	0.9
Iron (mg L^{-1})	0.36	0.18	0.23	0.12	0.14	0.52	0.15
Manganese (mg L^{-1})	0.002	0.007	0.040	0.018	0.002	0.002	0.002
Chloride (mg L^{-1})	0	0	3.5	0	0	2.5	15.0
Sulphate (mg L^{-1})	1.3	1.3	7.2	10.1	14.0	10.5	11.3
Phosphate (mg L^{-1})	0.020	0.128	0.092	0.093	0.083	0.065	0.068
Nitrate (mg L^{-1})	0.348	0.213	0.150	0.146	0.164	0.217	0.260
Silicate (mg L^{-1})	2.1	4.3	5.2	4.9	4.4	4.1	4.0

Site depth varied little whereas width increased quickly after site 3; thereafter it remained between 8 and 10 m (Table 8). Temperature fluctuated little but pH increased from 6.1 at site 1 to 7.8 at site 7. Alkalinity, conductance, magnesium, sodium, calcium, and potassium were all low at site 1. By site 2 they had increased swiftly with no real change occurring afterwards except for sodium which continued to increase downstream. Iron values were more variable with peaks at site 1 and 6 while manganese levels were consistently low. Sulphate followed the pattern of sodium since it increased downstream. Chloride, in contrast, showed no distinct pattern only being detectable at sites 3, 6, and 7 (table 8).

Levels of phosphate, nitrate, and silica were always high enough to be detected but displayed no longitudinal pattern.

Phytoplankton standing crops were always low (less than 0.5 mg m^2 chlorophyll) except at sites 1 and 3 (Fig. 7). The epipelic standing crop at site 1 was large at 43.1 mg m^{-2}. From site 2 onwards the epilithon dominated with maximum standing crops being found at site 4 and 5 (156 and 155 mg m^{-2} chlorophyll).

The algae found at each site are presented in Appendix 3. The sample for diatom identification from site 1 was lost. Of the non-diatomaceous algae none occurred at all sites. *Anabaena affinis* occurred at three sites, being important at all these, particularly site 1 (Table 9). Similarly, *Lyngbya aerugineo-caerulea* was most important everywhere, it was present constituting not less than 21.7% of the total community except at site 1. Both *Navicula graciloides* and *Achnanthes lanceolata* were present at sites 2 through 6. *Navicula graciloides* was

Table 9. The dominant algae found at each site in the Hangingstone River.

Site	Species	Percentage of Total Community (%)
1	*Anabaena affinis*	85.0
	Diatoms[a]	13.2
2	*Lyngbya aerugineo-caerulea*	37.0
	Anabaena affinis	22.3
	Navicula graciloides	14.9
	Navicula cryptocephala	7.1
	Achnanthes lanceolata	5.0
3	*Oscillatoria*	26.6
	Batrachospermum	23.4
	Lyngbya aerugineo-caerulea	21.7
	Navicula graciloides	12.3
4	*Lyngbya aerugineo-caerulea*	26.6
	Navicula graciloides	25.3
	Anabaena affinis	14.5
	Oscillatoria	12.1
	Pediastrum boryanum	7.7
5	*Oscillatoria*	55.0
	Epithemia sorex	12.1
	Batrachospermum vagum	7.7
6	*Lyngbya aerugineo-caerulea*	42.1
	Epithemia sorex	28.3
	Cocconeis placentula	8.8
	Synedra ulna	4.7

[a] Sample for species identifications lost.

important at sites 2, 3, and 4 while Achnanthes lanceolata was only at site 2.

Another important component at site 2 was Navicula cryptocephala which was not encountered again until sites 5 and 6. Synedra ulna was also consistently found at sites 2 through 6 but only in small amounts until site 6. Both Batrachospermum vagum and Cocconeis placentula occurred at sites 3, 5, and 6, with the former a dominant at sites 3 and 5 and the latter only at site 6 (Table 9). Oscillatoria sp. was an important component at sites 3, 4, and 5 (particularly site 5) while Epithemia sorex, although found at three consecutive sites, became important only at sites 5 and 6. Lastly, Pediastrum boryanum was encountered only at site 4 where it accounted for 7.7% of the total population.

Routine studies were conducted at 111° 21' 20" W long., and 56° 38' 30'' N lat (Figure 17, 18).

This site was selected on the basis of accessibility by helicopter and secondly it was upstream of potential effects from the town of Fort McMurray.

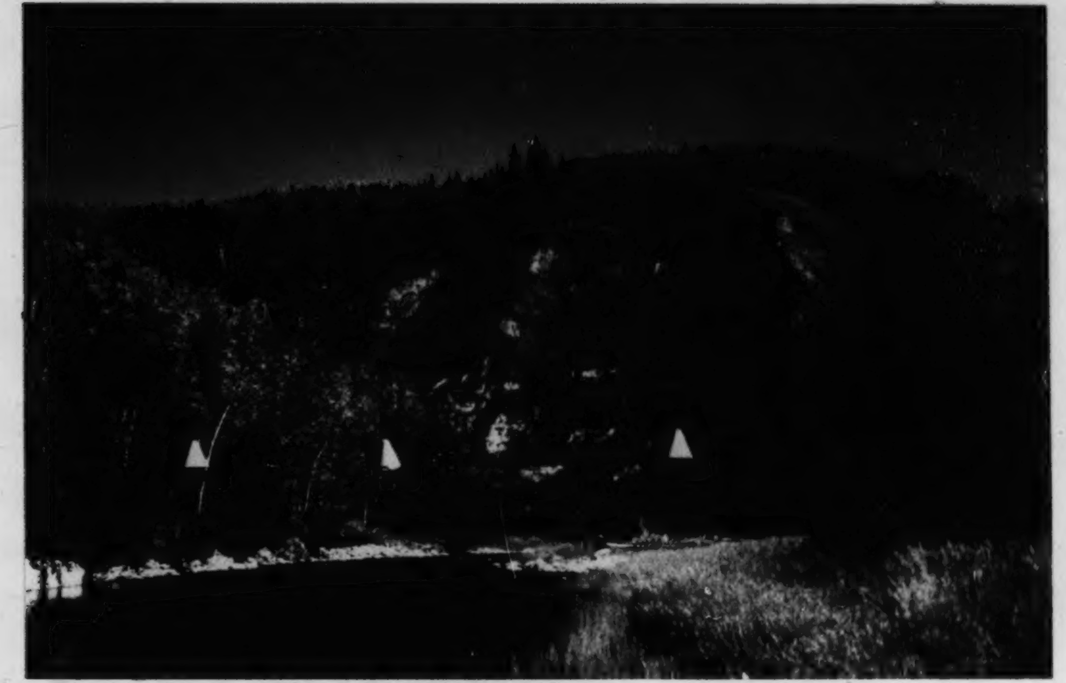


Figure 18. Hangingstone River, routine sampling site, showing characteristically steep river banks.

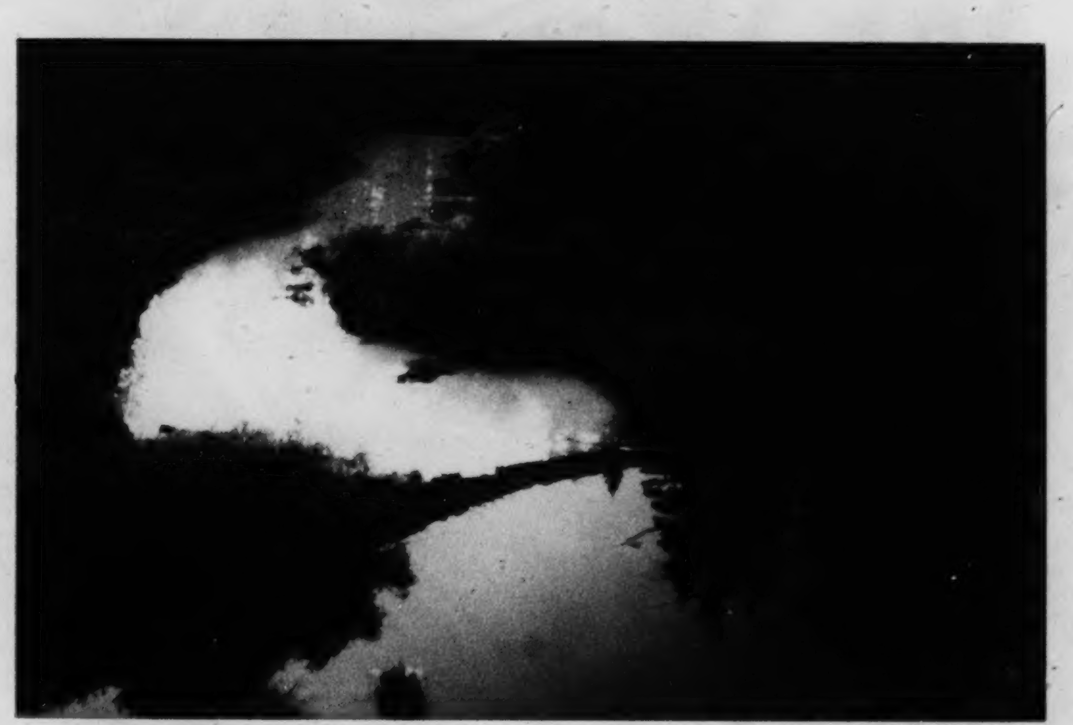


Figure 19. A Beaverdam in the uppermost reach of the MacKay River.

3.4 The MacKay River

The MacKay River is the longest river, draining an area of 5232 km^2. Again, its origins are in the muskeg, while in the lower reaches it drains silty till and lacustrine deposits. Like the Steepbank River, it flows through regions of exposed oilsand immediately north of the present Syncrude Canada Ltd. mining site. This river originates in the Birch Mountain Uplands, crossing the Algar Plain and Clearwater Lowlands (Figure 3). Black spruce-muskeg riparian vegetation dominates the uppermost reaches while boreal forest dispersed with muskeg predominates in the lower reaches. Beaver dams frequently retarded river flow in the upper reaches (Figure 19). The river substrata in the lower meandering reach of the MacKay River are flat sandstone and granite cobble, with some oilsand exposed to the river regime (Figures 20, 21, 22). The physical-chemical characteristics of the MacKay River are tabulated in the following Table 10 and 11.

Figure 20.
Map of the MacKay River showing
positions of the sampling sites.

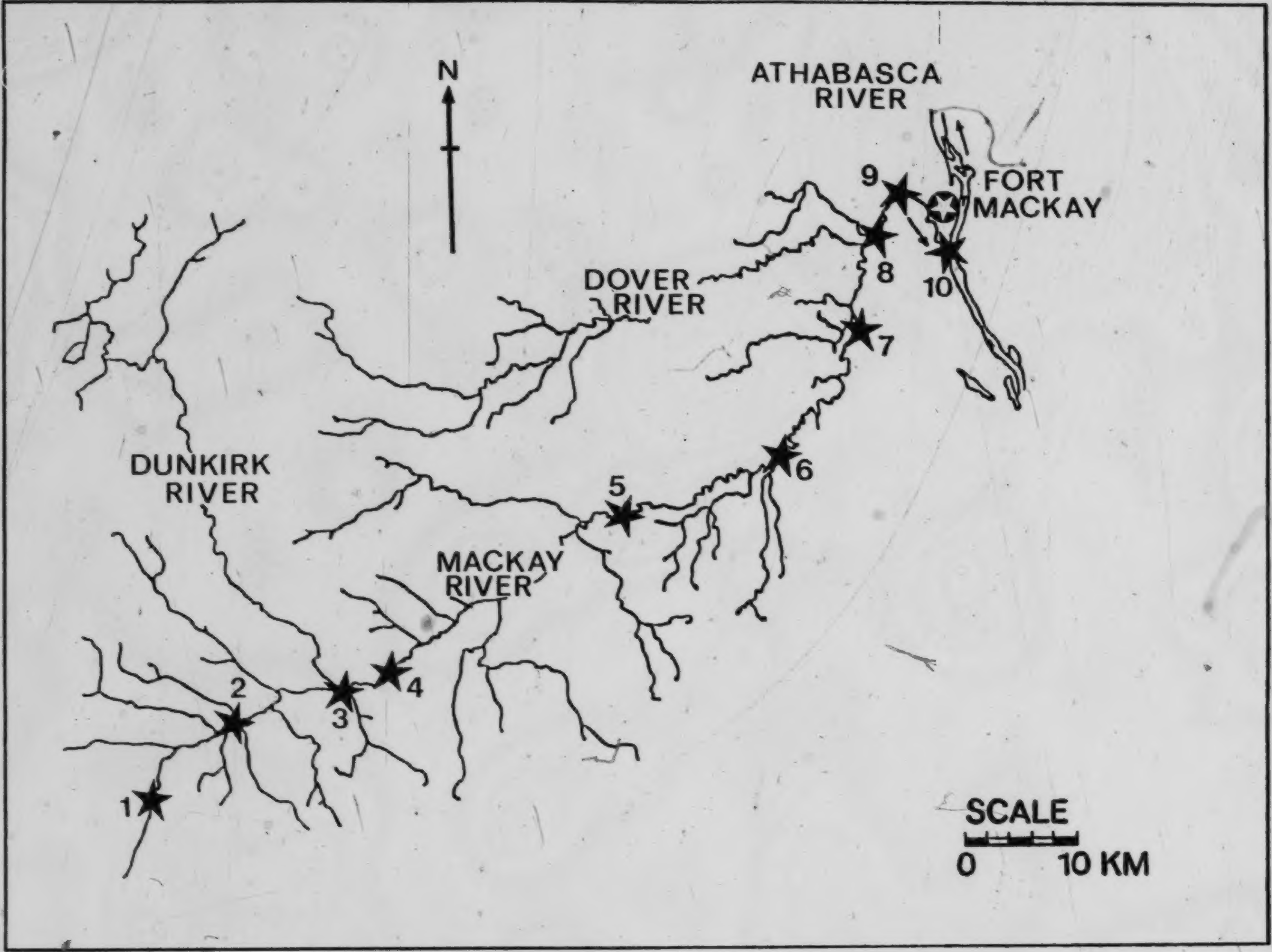

N
ATHABASCA
RIVER
9
FORT
MACKAY
8
10
DOVER
RIVER
7
DUNKIRK
RIVER
6
5
MACKAY
RIVER
4
2
3
1
SCALE
0
10 KM

Figure 21. Middle slow-flowing reach of the MacKay River.

Figure 22. The lower reach of the MacKay River illustrating extensive meandering before entering the Athabasca River.

Table 10: The latitude, longitude and brief site description of the MacKay River.

Site	Latitude	Longitude	Brief Description
1.	56° 40'N	112° 48'W	Situated in a slow flowing headwater stream meandering through muskeg. Substratum-organic mud. Many beaver dams result in slow flowing water and numerous pools.
2.	56° 44'N	112° 41'W	Very similar to Site 1 in all features
3.	56° 46'N	112° 32'W	Here rock first appears. Riffle area, water swiftly flowing; substratum -cobble (10 to 50 cm diameter). Located immediately below the confluence of the MacKay and Dunkirk rivers. Aquatic mosses and macroalgae were visible.
4.	56° 46'N	112° 28'W	Comprise both pool and riffle areas; substratum-cobbled (very similar to Site 3).
5.	56° 56'N	112° 04'W	Nearly vertical banks (1 m high) line the river; riffle area, substratum -cobble (5 to 30 cm diameter) otherwise similar to Sites 3 and 4.
6.	56° 58'N	111° 53'W	Banks sloped gently, rich in oil sand; shallow water; riffle area-substratum cobble (5 to 30 cm in diameter).
7.	57° 06'N	111° 46'W	Similar to Site 6 except vertical banks.

Table 10: Continued.

Site	Latitude	Longitude	Brief Description
8.	57° 10'N	111° 45'W	Situated immediately downstream of the Dover River. Water swiftly flowing; riffle region (similar to Site 7).
9.	57° 10'N	111° 36'W	As above for Sites 7 and 8.
10.	57° 10'N	111° 38'W	Situated at the mouth of the MacKay River as it enters the Athabasca River. Substratum variable with cobble dominating but mud and sand were also present

Table 11. Physico-chemical conditions at each site in the MacKay River during July, 1978.

	Sites									
PARAMETERS	1	2	3	4	5	6	7	8	9	10
Depth (cm)	90	125	55	35	35	15	50	125	50	65
Width (m)	3.5	4.5	5.0	7.0	6.0	8.0	7.0	10.0	12.0	15.0
Temperature (^{o}C)	12.0	12.0	11.8	12.5	13.2	14.0	13.2	12.8	13.2	13.3
pH	6.8	6.9	7.2	7.7	7.9	8.1	8.2	8.4	8.4	8.3
Alkalinity (meq L^{-1})	2.10	2.35	2.62	2.62	2.40	2.90	3.22	3.50	3.78	3.50
Conductance (mS/m)	22.0	24.0	27.5	28.5	27.0	31.5	37.0	43.5	43.5	40.0
Magnesium (mg L^{-1})	8.4	9.0	11.7	11.3	11.0	11.9	14.9	17.9	17.0	15.6
Calcium (mg L^{-1})	19.8	24.9	28.2	26.1	26.8	25.8	28.5	27.6	27.9	28.5
Sodium (mg L^{-1})	19.4	21.2	17.5	24.0	19.0	31.6	37.6	54.4	54.4	44.9
Potassium (mg L^{-1})	0.5	0.3	1.4	1.5	1.5	1.6	1.8	2.7	2.1	1.9
Iron (mg L^{-1})	0.18	0.42	0.19	0.10	0.05	0.05	0.04	0.04	0.03	0.02
Manganese (mg L^{-1})	0.026	0.149	0.009	0.003	0.009	0.005	0.002	0.002	0.002	0.007
Chloride (mg L^{-1})	0	0	0	0	0	0.5	6.5	3.6	19.0	16.5
Sulphate (mg L^{-1})	7.2	0	20.4	22.2	21.0	24.0	35.3	25.8	31.5	29.0
Phosphate (mg L^{-1})	0.037	0.106	0.034	0.019	0.004	0.006	0.003	0.005	0.003	0.003
Nitrate (mg L^{-1})	0.294	0.348	0.169	0.184	0.187	0.178	0.155	0.138	0.134	0.133
Silicate (mg L^{-1})	3.2	4.3	0.6	0.3	0.4	0.9	0.9	2.1	1.3	1.5

Water depth was greatest in the headwater region and near the Athabasca River (Table 11). In between, the river was much shallower. River width generally increased downstream fairly steadily. Temperature changed little, but pH increased in a downstream direction from 6.8 to a peak of 8.4 at site 1 and 8 respectively. Total alkalinity, conductance, magnesium, calcium, sodium, and potassium concentrations all increased in a downstream direction. Iron and manganese did not follow this pattern; instead their longitudinal distribution was irregular. Chloride remained undetectable until site 6. From here to site 9 it steadily increased in concentration. Sulphate, although detectable at site 1, was not at site 2, but values at site 3 were nearly three times that of site 1. The values remained at this level with two small peaks at sites 7 and 9.

Phosphate concentrations were highest at sites 1 through 4. Afterwards they decreased and remained low. Silica levels were also initially high falling at site 3 with no sigificant increase occurring until site 8.. Nitrate concentrations in contrast were always high, but again generally increased in a downstream direction (Table 11).

The phytoplankton standing crop was initially high at site 1 (9.5 mg m^{-2} chlorophyll a) but decreased quickly downstream (Figure 7) remaining low at all other sites. The epipelon comprised the major benthic community at sites 1 and 2 with standing crops of 16.7 and 2.0 mg m^{-2} chlorophyll a. Afterwards the epilithon became dominant. No longitudinal standing crop pattern was evident and levels were generally high ranging from 30 to 69 mg m^{-2} chlorophyll a with one exception at site 7 where it was less than 10 mg m^{-2} chlorophyll a.

The algae found at each site are listed in Appendix 4. Only

Table 12. The dominant algae found at each site in the MacKay River.

Site	Species	Percentage of Total Community (%)
1	_Lyngbya aerugineo-caerulea_	24.8
	Oscillatoria sp.	17.7
	Navicula cryptocephala	14.5
	Pinnularia gibba	7.5
	Anabaena affinis	7.1
	Chlorella vulgaris	7.1
	Navicula pupula	5.6
2	_Chlamydomonas_ spp.	50.0
	Chlorella vulgaris	16.7
	Rhodomonas minutum	13.3
	Trachelomonas	6.7
3	_Anabaena affinis_	70.6
	Chlamydomonas spp.	11.7
	Cryptomonas ovata	8.9
	Cocconeis pediculus	3.0
	Cocconeis placentula	3.0
4	_Lyngbya aerugineo-caerulea_	65.4
	Amphipleura lindheimeri	7.8
	Oedogonium sp.	4.6
	Navicula cryptocephala	4.4
	Gomphonema lanceolatum	2.4
	Nitzschia recta	2.4
5	_Lyngbya aerugineo-caerulea_	40.1
	Chlorella vulgaris	19.0
	Fragilaria vaucheriae	9.6
	Oedogonium sp.	8.3
	Epithemia sorex	6.4
	Cocconis pediculus	5.0

Table 12. Concluded.

Site	Species	Percentage of Total Community (%)
6	Batrachospermum vagum	37.8
	Cladophora glomerata	15.4
	Cocconeis pediculus	11.0
	Gomphospaeria aponina	7.3
	Lyngbya aerugineo-caerulea	4.5
	Epithemia sorex	4.4
7	Lyngbya aerugineo-caerulea	12.3
	Scendesmus acutiformis	11.5
	Scenedesmus bijuga	8.2
	Gomphosphaeria aponina	6.6
	Stigeoclonium sp.	4.9
	Navicula cryptocephala	4.8
	Cocconeis placentula	4.3
	Ankistrodesmus falcatus	4.1
	Cladophora glomerata	4.1
8	Anabaena affinis	22.4
	Chlorella vulgaris	10.9
	Cladophora sp.	9.2
	Lyngbya aerugineo-caerulea	5.9
	Pediastrum biradiatum v. emarginatum f. convexum	5.3
	Cocconeis placentula	4.2
	Achnanthes lanceolata	4.2

Cocconeis placentula was found at all sites in the MacKay River contributing significantly at sites 3, 7, and 8 (Table 12). Seven other algae were found at all but one site, namely *Anabaena affinis*, *Lyngbya aerugineo-caerulea*, *Chlamydomonas* spp., *Cladophora glomerata*, *Cocconeis pediculus*, *Navicula cryptocephala* and *Navicula radiosa*. Only *Navicula radiosa* did not contribute significantly at any site. *Lyngbya aerugineo-caerulea* was dominant at most sites ranging between 4.5 and 65.4% of the total population. Peak development occurred at Sites 4 and 5. *Cladophora glomerata* and *Navicula cryptocephala* were both absent from site 2. The former did not assume importance until site 6 remaining so at sites 7 and 8 while the latter was important at sites 1, 4, and 7 with peak contribution at site 1. *Anabaena affinis* and *Chlamydomonas* spp. were both absent from site 5. *Anabaena affinis* occurred at three sites spread over the entire length of the river. *Chlamydomonas* spp. contributed most at sites 2 and 3. The last of the group, *Cocconeis placentula* was only absent from site 1, contributing significantly at sites 3, 5, and 6.

Chlorella vulgaris was the next most widely distributed alga contributing significantly at sites 1, 2 and 5. Three algae *Achnanthes lanceolata*, *Ankistrodesmus falcatus*, and *Gomphonema lanceolatum*, which contributed significantly at at least one site were also found at a total of five sites. The former two were most prominent at sites 8, and 7, while *Gomphonema lanceolatum* peaked at site 4. A large number of algae were found at four sites contributing significantly to at least one site. This group included *Scenedesmus acutiformis*, *Scenedesmus bijuga*, and *Stigeoclonium* sp. all of which were prominent at site 7,

Oedogonium sp. and *Nitzschia recta*, both important at site 4 and

Epithemia sorex, prominent at both sites 5 and 6.

Three algae were present at only three sites but were significant components of the total community at at least one site. These included *Pinnularia gibba*, *Fragilaria vaucheriae*, and *Gomphosphaeria parvulum*. A further six algae, namely, *Oscillatoria* spp, *Rhodomonas minutum*, *Trachelomonas* sp., *Amphipleura lindheimeri*, *Cryptomonas ovata* and *Pediastrum biradiatum* v. *emarginatum* f. *convexum*, contributed significantly but have an even more limited distribution being found at just two sites. Finally, two algae were found at only one site but were important components of the community namely, *Batrachospermum vagum* and *Navicula pupula*.

Routine studies were conducted at 111° 43' 40" W long., and 57° 11' 50" N lat. This site was selected due to its proximity to a study of the MacKay River fish fauna conducted under the direction of W.A. Bond and K. Machniak during 1978 and 1979. Sandstone, granite and oilsand substrates were available at this site for investigation of the epilithon (Figure 23).

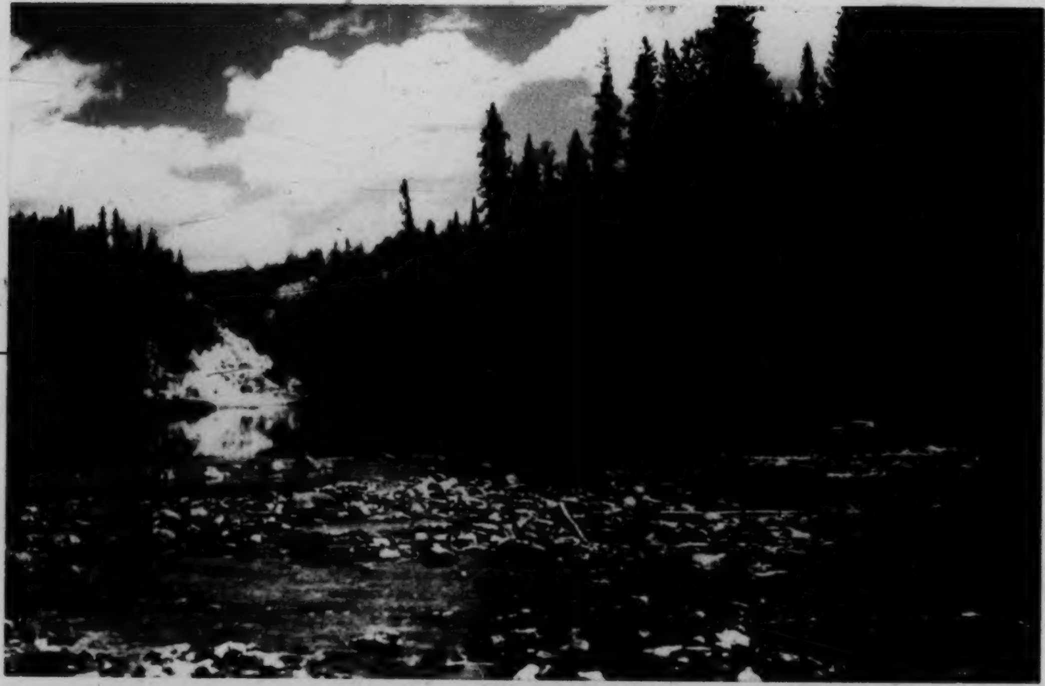


Figure 23. The MacKay River routine sampling sites.

Figure 24. The Ells River at its origin in the Gardiner Lakes area.

3.5 The Ells River

The Ells river is the only river originating from a lake and is much larger at its source than the others.

It drains hummocky moraine, till sands, gravels and muskeg in the upper reaches, while the lower reaches drain clay, silty till and muskeg. Draining an area of 2700 km^2, it descends from the Birch Mountains, crossing the Algar Plain and Clearwater Lowlands (Figure 3, 24). Riparian vegetation varies from boreal forest and muskeg to muskeg black spruce associations. Sandstone and granite cobble predominate throughout the length of the river. Arctic grailing Thymallus arcticus (Pallas) were particularly abundant in the uppermost reaches of the Ells River.

Figure 25 and Table 13 depict the specific site location and description of the Ells River during the 1979 longitudinal survey.

Physical-chemical characteristics of the Ells River are presented in the following Table 14.

Figure 25.
Map of the Ells River showing positions
of the sampling sites.

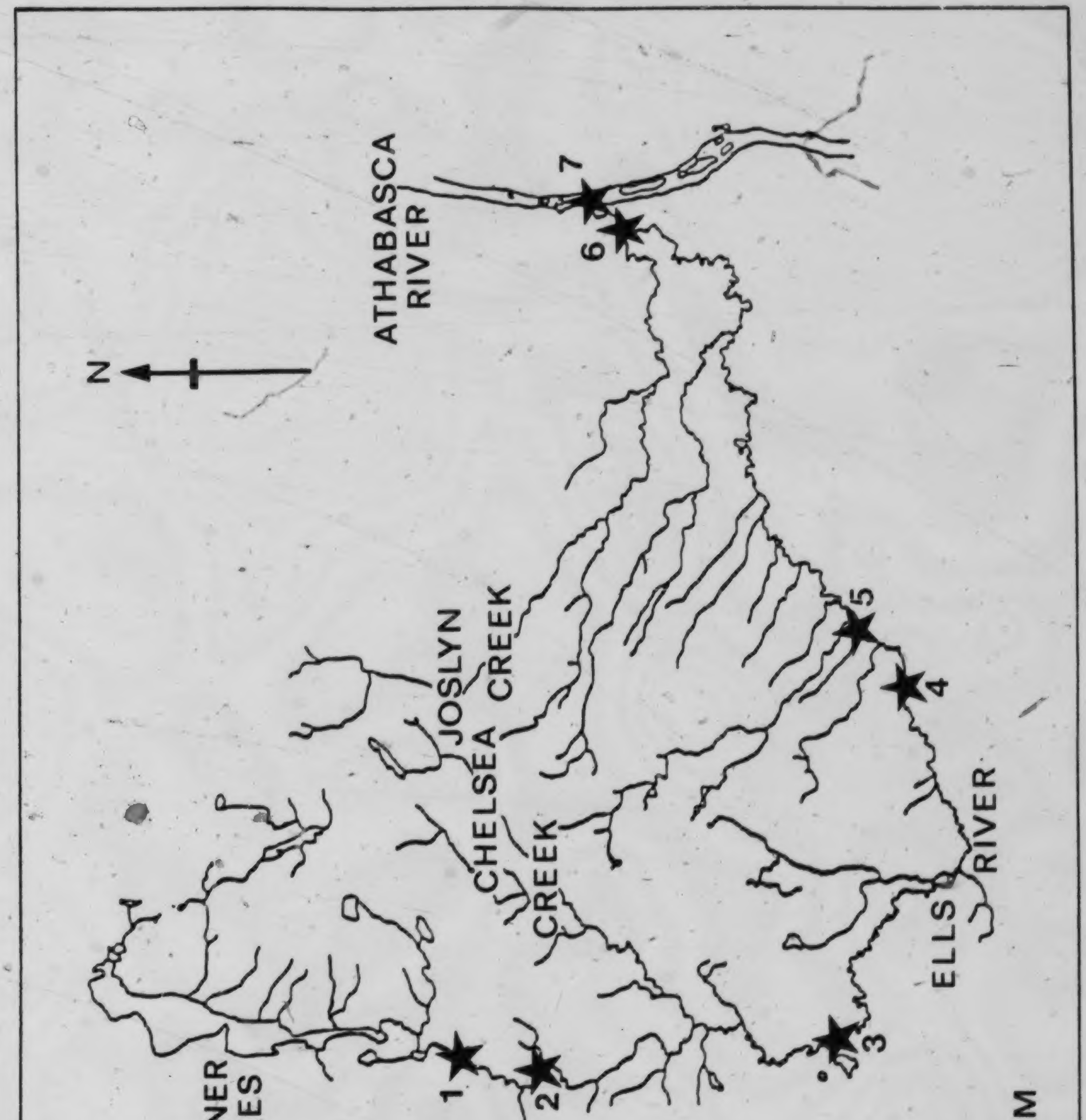

N
ATHABASCA
RIVER
7
6
JOSLYN
CREEK
CHELSEA
CREEK
5
4
GARDINER
LAKES
1
2
3
ELLS
RIVER
SCALE
0
10 KM

Table 13: The latitude, longitude and brief site description for the Ells river

Site	Latitude	Longitude	Brief Description
1	57° 24'N	112° 32'W	Situated immediately downstream of the Gardiner Lakes District of the Birch Mountains. Water flow slow; substratum a mixture of sand, mud, and cobble (12 cm diameter).
2	57° 21'N	112° 33'W	Here the river is narrower than at Site 1. Water flow more rapid; riffle area; substratum-cobble.
3	57° 11'N	112° 32'W	Similar to Site 2 except banks nearly vertical and up to 2 m high. Riffle area; water fast flowing; substratum cobble and boulders (14 to 40 cm diameter).
4	57° 09'N	112° 10'W	Riffle area; water fast flowing; substratum-cobble (5 to 25 cm diameter) and gravel. River banks again steep rising to a height of 6 m above the stream bed.
5	57° 11'N	112° 06'W	Similar to Site 4 with fast flowing water; substratum ranged from cobble, to boulder and flat rocks. Banks rose steeply to an estimated height of 40 m.
6	57° 17'N	111° 42'W	As Site 5.
7	57° 18'N	111° 42'W	Situated at the confluence of Ells and Athabasca Rivers. Substratum mixed cobble and muddy sand rich in oil sand.

Table 14: Physical-chemical conditions at each site in the Ells River. during 1978.

	Site						
	1	2	3	4	5	6	7
Depth (cm)	60	40	60	50	40	50	150
Width (m)	60	7	10	12	13	14	20
Temperature (^{o}C)	8.8	10.6	11.8	12.2	13.0	15.0	20.0
pH	6.6	6.8	7.0	7.2	7.4	7.4	7.4
Alkalinity (meq L^{-1})	0.79	0.83	0.86	0.90	0.98	0.98	0.98
Conductance (mS/m)	11.0	10.8	11.0	12.0	12.5	12.5	14.5
Magnesium (mg L^{-1})	2.5	2.3	2.7	2.8	3.0	3.0	4.2
Calcium (mg L^{-1})	14.2	13.4	14.9	15.9	16.2	17.2	22.9
Sodium (mg L^{-1})	1.5	1.6	1.7	2.1	2.5	2.7	2.2
Potassium (mg L^{-1})	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Iron (mg L^{-1})	0.698	0.070	0.070	0.081	0.750	0.86	16.8
Manganese (mg L^{-1})	0	0.007	0.007	0.007	0.004	0.004	0.014
Chloride (mg L^{-1})	0	0	0	0	0	0	0
Sulphate (mg L^{-1})	5.3	6.5	7.0	7.8	7.5	8.8	11.0
Phosphate (mg L^{-1})	0.011	0.012	0.013	0.017	0.018	0.020	0.013
Nitrate (mg L^{-1})	0.110	0.112	0.102	0.102	0.115	0.107	0.265
Silicate (mg L^{-1})	2.1	2.1	2.1	2.0	2.1	2.0	3.0

Water depth varied little even in the headwater area and was deepest at site 7. However, marked variation in width occurred as it was 60 m wide at site 1 (Figure 25). This river originates from a lake and this location represented the first area that could be considered lotic. By site 2 it had narrowed to 7 m after which it gradually widened to 20 m by site 7 (Figure 26).

The headwater temperatures were cooler than the lower reaches. In fact site 1 and 7 differed by 11.2°C. pH and alkalinity fluctuated little; both gradually increased in a downstream direction. Calcium, magnesium and sodium followed a similar pattern while potassium levels did not alter. Iron levels fluctuated irregularly but a massive peak occurred at site 7. Manganese levels were low and hardly changed while chloride was detectable at only site 4. Sulphate slowly increased in a downstream direction such that by site 7 levels were about twice that found at site 1. Phosphate, nitrate and silicate fluctuated little and irregularly.

Phytoplankton standing crops were generally low fluctuating irregularly throughout the length of the river (Fig. 7). The epipelon was only important at site 1 where a standing crop of 5.8 mg m^{-2} chlorophyll a were found. At this same site the largest epilithic standing crop was found 68.9 mg m^{-2} chlorophyll a). By site 2 it had decreased to 11.7 mg m^{-2} chlorophyll a; similar standing crops were found at the next two sites, after which the standing crops were very tiny.

The algae found at each site are presented in Appendix 5. In the Ells River, only Diatoma vulgaris v. grandis and Nitzschia dissipata were found at all sites (Appendix 5). Both were found in significant numbers; *Diatoma vulgare v. grandis* at sites 2 and 3, and *Nitzschia dissipata* at Site 5 (Table 15). Three other dominant algae were widely distributed and found at all but one site: *Cocconeis placentula*, present at all but site 4 and dominant at sites 3 and 6; *Cymbella ventricosa*, absent from just site 6 and dominant at sites 1 and 5; and *Navicula cryptocephala*, absent from only site 1 and dominant at site 6.

Algae such as *Lyngbya aerugineo-caerulea*, *Chlorella vulgaris*, *Achnanthes lanceolata*, *Cyclotella kutzingianum*, *Cymbella sinuata*, *Navicula minima v. atomoides*, and *Diatoma vulgare* had a more limited distribution but were present in significant numbers at at least one site (Table 15). *Lyngbya aerugineo-caerulea*, in particular, was numerically the most important at sites 1, 2, and 4. Another feature of this river was the larger number of species contributing to the overall community (eg. sites 3 and 6). In complete contrast, *Lyngbya aerugineo-caerulea* made up almost the entire community at site 4.

Routine investigations of the Ells River were conducted at 112° 33' 15" W Long., and 57° 21' 10" N Lat. This site was selected on the basis of accessibility by helicopter, and secondly, it represented an area unaffected by mining developments both present and future (Figure 27).

Table 15. The dominant algal species found at each site in the Ells River.

Site	Species	Percentage of Total Community (%)
1	Lyngbya aerugineo-caerulea	40 .1
	Cymbella ventricosa	15.6
	Chlorella vulgaris	15.6
	Achnanthes lanceolata	3.9
2	Lyngbya aerugineo-caerulea	84.1
	Gomphonema olivaceum	9.6
	Diatoma vulgare v. grandis	2.0
3	Gomphonema olivaceum	31.6
	Diatoma vulgaris v. grandis	10.5
	Nitzschia recta	10.5
	Cocconeis placentula	7.9
	Fragilaria pinnata	5.3
	Cyclotella kutzingianum	5.3
4	Lyngbya aerugineo-caerulea	98.2
5	Achnanthes lanceolata	17.3
	Nitzschia dissipata	17.3
	Cymbella sinuata	11.8
	Cymbella ventricosa	11.8
	Navicula minima v. atomoides	11.8
6	Navicula cryptocephala	36.3
	Cocconeis placentula	9.0
	Cyclotella meneghiniana	9.0
	Diatoma vulgare	9.0
	Fragilaria pinnata	9.0
	Gomphonema olivaceum	9.0
	Nitzschia dissipata	9.0
	Nitzschia palea	9.0

Figure 26. Photo of the Ells River flowing down from the Birch Mountain Uplands.

Figure 27. The Ells River routine sampling site.

4. Results

4.1 Comparison of Methods for Studying Eplithon

4.1.1 Quadrat vs Scrape Technique (1977)

Very few organisms are continuously distributed through their environment due to the presence of areas offering quite different kinds of conditions. Moreover it was not known how various sampling techniques could affect estimates of epilithic standing crops. Therefore during the period May 13, 1977 through January 20, 1978 epilithic standing crop estimates were compared using the quadrat and scrape techniques among three Muskeg River microhabitats. Twenty sample dates were compared for Shore (15 cm depth), midstream and riffle habitats. Table 16 presents the mean values for variables and statistical tests.

Technique		Quadrat Chlorophyll a m^{-2}			Scrape Chlorophyll a m^{-2}		Significance Quadrat vs Scrape
	Mean cv.	Mean	Range	Mean cv.	Mean	Range	
Shore	27	19.2	(3.31-135.5)	27	24.0	(1.0-59.0)	N.S.
Midstream	28	16.7	(2.9 - 56.5)	22	31.9	(9.2-56.4)	Sig (p .01)
Riffle	33	19.8	(2.49- 73.3)	27	36.8	(6.0-88.1)	N.S.

cv = coefficient of variation

(% deviation from the mean $\frac{\text{Standard Deviation}}{\text{Mean}}$ X 100)

Table 16. Microhabitat mean and range of standing crops, deviation from the mean (cv) and probability of significant differences between sampling techniques. (students t-test) (1977)

Figure 28.
The seasonal variation of epilithic algal standing crops derived by various sampling techniques (1977 - 1979).

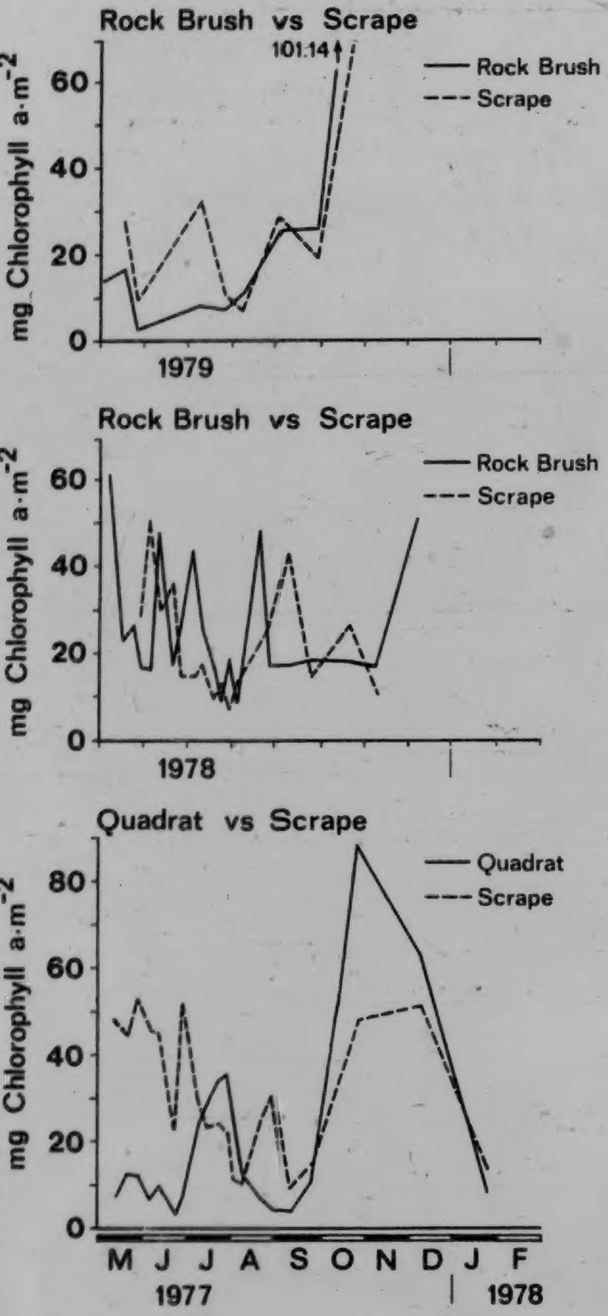
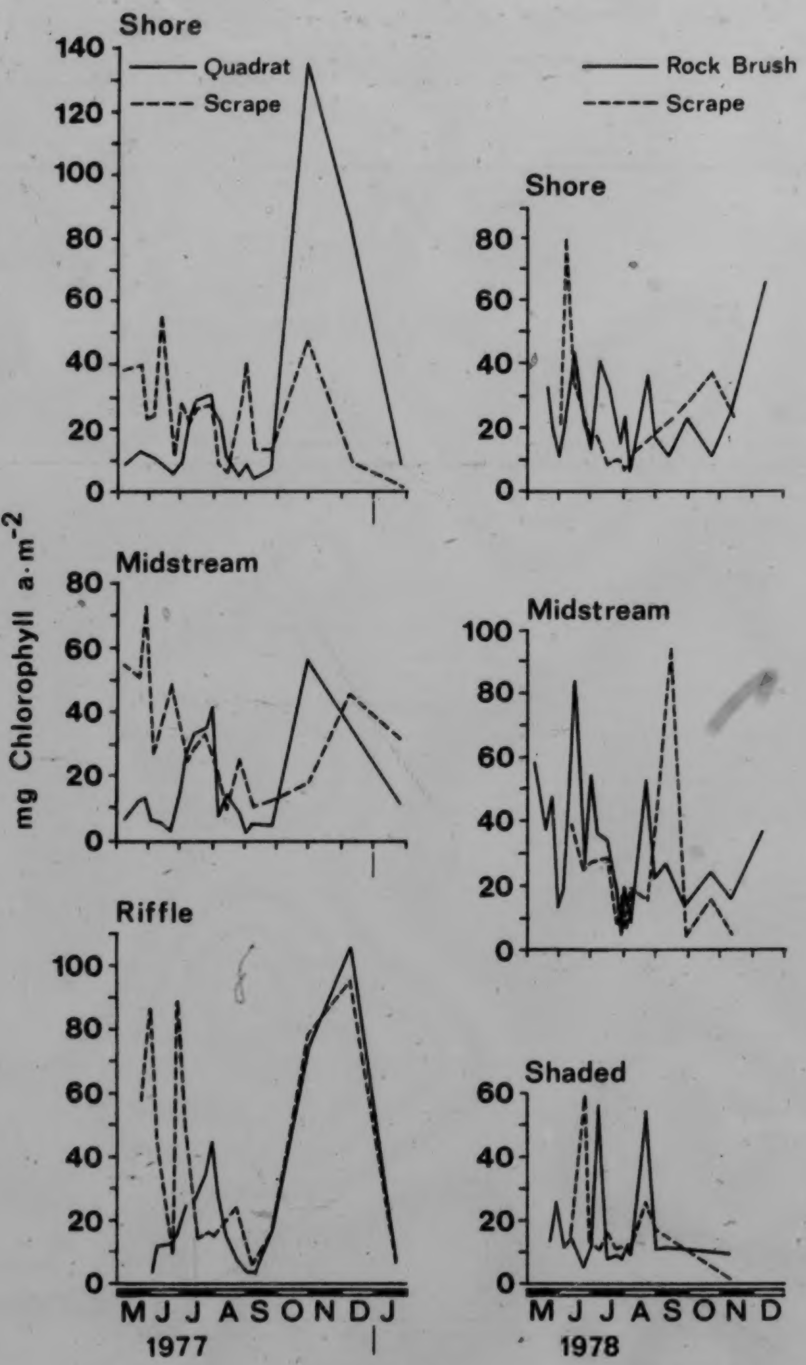

Rock Brush vs Scrape
101.14
Rock Brush
Scrape
mg Chlorophyll a·m-2
0
20
40
60
1979
Rock Brush vs Scrape
Rock Brush
Scrape
mg Chlorophyll a·m-2
0
20
40
60
1978
Quadrat vs Scrape
Quadrat
Scrape
mg Chlorophyll a·m-2
0
20
40
60
80
M J J A S O N D J F
1977
1978

Figure 29.
Microhabitat variation of epilithic algal standing crops (chlorophyll a m^{-2}) in the Muskeg River during 1977 and 1978.


Shore
Quadrat
Scrape
Rock Brush
Scrape
Shore
Midstream
Midstream
Riffle
Shaded
mg Chlorophyll a·m-2
140
120
100
80
60
40
20
0
M J J A S O N D J
1977
M J J A S O N D
1978

The quadrat sampling technique yielded a lower mean standing crop estimate than the scrape technique for the shore region (15 cm depth), however, the differences were not significant. The seasonal fluctuations (mean of midstream, shore and riffle) are shown in Figure 28. During May through early July as well as late August the scrape technique yielded a higher standing crop estimate. Conversely the quadrat technique yielded higher standing crops during late July and again October through January (Figure 28). With the exception of the riffle habitat the range of values found were higher using the quadrat technique in both the midstream and shore locations. The mean coefficient of variation for the entire study was slightly higher in the riffle and midstream when the quadrat technique was compared among microhabitats. The scrape technique however yielded data with the same percent deviation from the mean in both the shore and riffle. Both the scrape and quadrat technique chlorophyll a results deviated least from the mean in the midstream location (Figure 29). Analysis of variance (ANOVA) indicated no significant difference between the two techniques and among the standing crops found in each microhabitat.

4.1.2 Single Rock Brush vs Scrape Technique (1978)

Throughout 1978 (May-December) the use of the scrape technique was again continued in order to estimate epilithic algal standing crop. However, instead of the quadrat technique single rocks (15 to 20) were collected from shore, midstream and the artificially shaded microhabitat. The entire community was removed from each rock and subsampled to determine epilithic algal standing crop. The single rock brush and scrape technique for estimating epilithic algal standing crops were compared. The data for this comparison are contained in Table 17 and Figures 28 and 29.

Technique	Single Rock Brush Chlorophyll a m^{-2}			Scrape			
	Mean cv	Mean	Range	Mean cv	Mean	Range	Significance Brush vs Scrape
Shore	63	26.6	(7.5-65.8)	61	22.7	(5.8-36.5)	($p < .05$)
Midstream	58	31.1	(4.7-84.9)	65	24.1	(3.7-94.2)	N.S.
Midstream (shaded)	75	16.8	(5.8-55.9)	70	16.9	(0.5-58.1)	N.S.

cv = coefficient of variation

(% deviation from the mean $\frac{\text{Standard Deviation}}{\text{Mean}}$ X 100)

Table 17. Microhabitat mean and range of standing crops, deviation from the mean (cv) and probability of significant differences between sampling techniques (students t-test) (1978).

Although the single rock brush and scrape techniques yielded similar mean standing crop estimates among each of the microhabitats examined, specific differences were evident when seasonal patterns were compared (Figures 28, 29). The rock brush technique yielded higher values during May, July, August and after November (Figure 28). The scrape technique yielded higher estimates of mean standing crop primarily during the fall (Sept-Nov).

Standing crop estimates were lower in the midstream shaded than the unshaded river locations (Table 17). The values which exhibited the highest percent deviation from the mean were found in the shaded microhabitat. Analysis of variance (ANOVA) failed to show significant differences in algal standing crop among the various microhabitats. Paired student t-tests did however indicate a significant difference between the two techniques when applied to the shallow shore microhabitat only.

4.1.3 Single Rock Brush vs Scrape Technique (1979)

During 1979, the single rock brush technique was again employed to estimate epilithic algal standing crops; however, microhabitats were not differentiated; instead, rocks were collected at random along transects from shore to shore in the Muskeg River. The brushing technique provided a higher estimate of epilithic algal standing crop (Figure 28). Differences were most pronounced during June and July. The scrape technique yielded a mean 24.8 mg chl *a* m^{-2}, range (5.7-76.3 mg chl *a* m^{-2}), the brush technique a mean of 26.2 mg chl *a* m^{-2} (range 1.3-101.1 mg chl *a* m^{-2}). Analysis of variance (ANOVA) showed no significant difference ($p < 0.05$) between the two techniques for estimating epilithic algal standing crop.

4.2 Substratum Comparison: Oilsand/Rock

During 1977, visual observations indicated that naturally occurring bitumous substratum (oilsand) appeared to support more *Nostoc commune* than rock substratum. Closer examination using chlorophyll a as a measure of epilithic algal standing crop indicated that the oilsand supported an average 27.7 mg chlorophyll *a* m^{-2} while the rock supported an average 60.1 mg chlorophyll a m^{-2}, during the period July 13 through December 9, 1977. A similar trend was again found during 1978 with oilsand averaging 10.8 and rock averaging 48.5 mg chlorophyll *a* m^{-2}. The rock supported significantly higher (p .05) standing crops. The apparent abundance of Cyanophycean algae associated with oilsand and rock substratum was further examined with respect blue-green algal numbers and nitrogen fixation. The findings will be discussed later.

4.3 Seasonal Patterns or Temporal Changes

4.3.1 Physical and Chemical Changes

The following is a presentation of the seasonal dynamics of physical and chemical parameters examined during investigation of the Muskeg, Steepbank, Hangingstone, Ells and MacKay rivers.

4.3.1.1 Temperature

The seasonal dynamics of water temperature were similar for the five rivers investigated. Maximum temperatures occurred each July and thereafter declined (Figure 30). Only during 1977 in the Steepbank and Muskeg Rivers did any marked fluctuation occur. The MacKay River exhibited the greatest overall mean temperature (9.6°C), and the widest temperature range (0-23°C). During the winter period and the resultant low temperatures (November - April), ice depths of up to 76.3 cm were encountered on the Ells River.

4.3.1.2 Discharge

Discharge patterns were similar in each river (Figure 31). In the MacKay, Ells and Steepbank Rivers maxima occurred in September, 1978 and May, 1979, with the latter being greater. In contrast, these maxima were of comparable size in the Hangingstone and Muskeg Rivers. Discharge during 1977 in both the Muskeg and Steepbank Rivers were much lower than during 1978 and 1979. Discharge in the MacKay River was greater than any of the remaining four rivers.

4.3.1.3 Specific Conductance

Mean specific conductance in the five rivers investigated ranged from 10.9 to 23.4 mS/m (Figure 36). It was greatest in the Muskeg River but remained lowest and essentially constant in the Ells River, (i.e. 10.9 ± 0.2 mS/m) throughout the study period.

Figure 30.
Water temperatures in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.

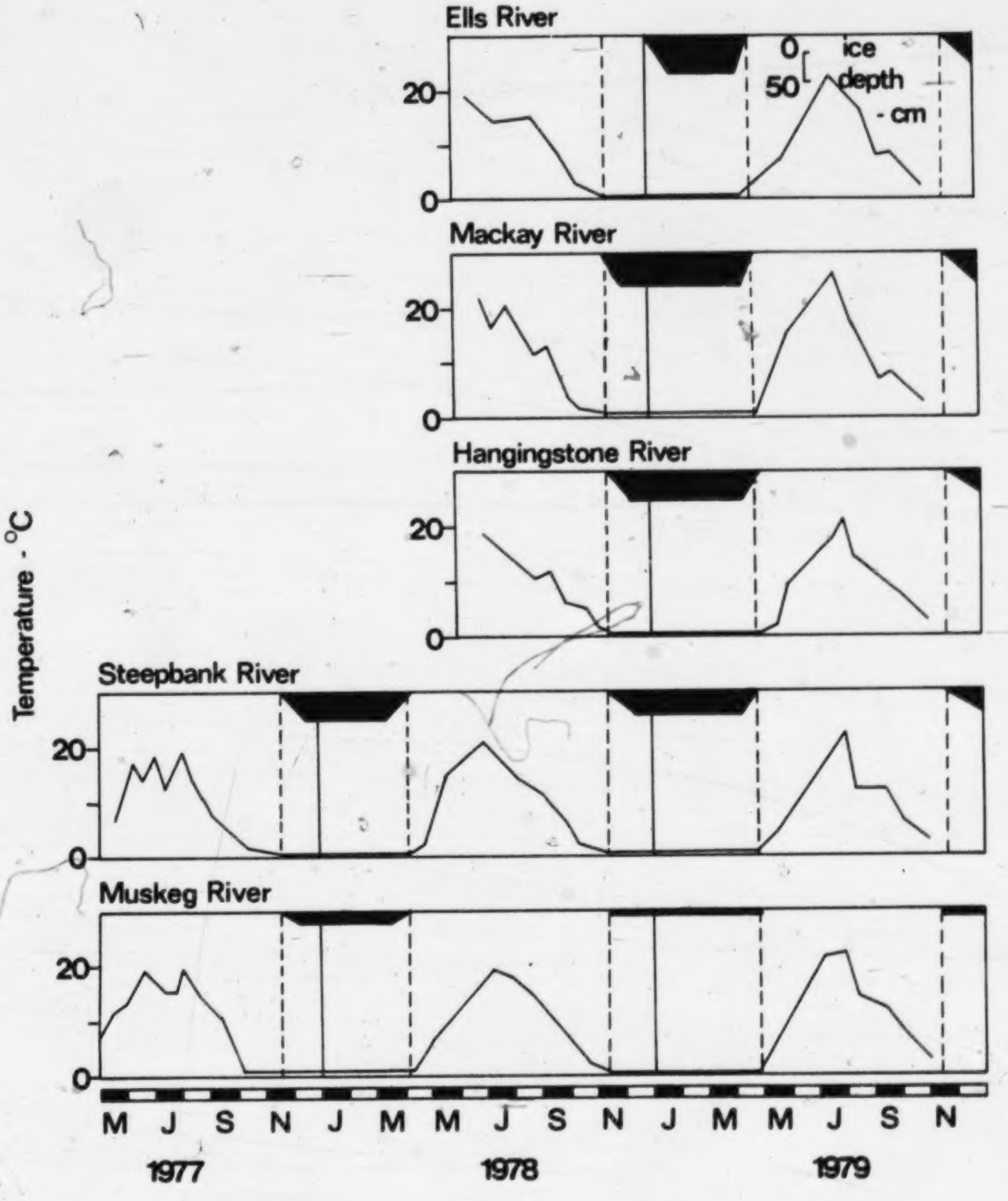

Ells River
Mackay River
Hangingstone River
Steepbank River
Muskeg River
Temperature - °C
0
20
0
50
ice depth - cm
M
J
S
N
J
M
M
J
S
N
J
M
M
J
S
N
1977
1978
1979

Figure 31.
Discharge (m^3 s^{-1}) in Ells, MacKay, Hangingstone,
Steepbank, and Muskeg Rivers.

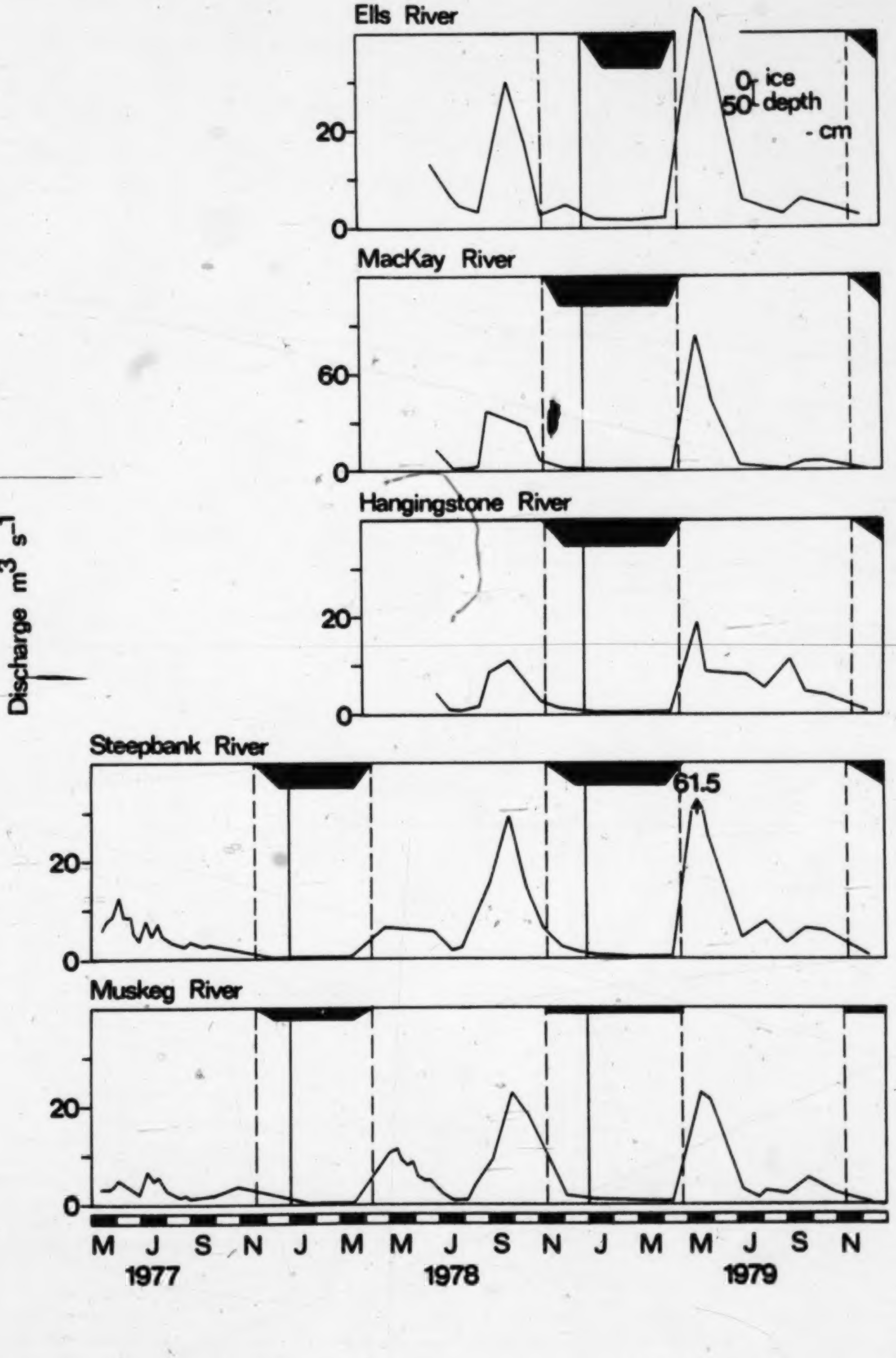
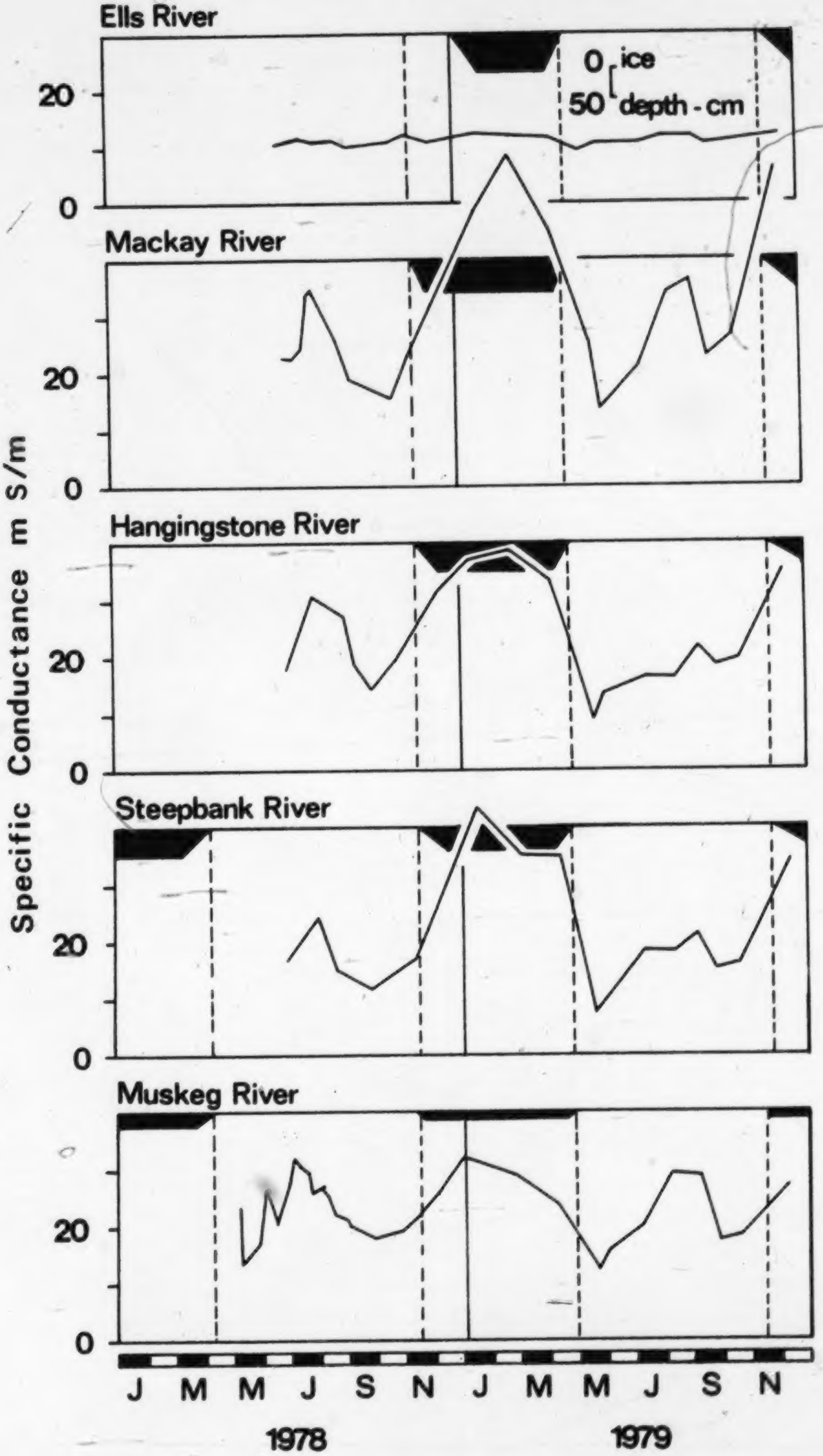

Ells River
0- ice
50- depth
- cm
20
0
MacKay River
60
0
Hangingstone River
20
0
Steepbank River
61.5
20
0
Muskeg River
20
0
Discharge m^3 s^{-1}
M J S N J M M J S N J M M J S N
1977
1978
1979

Figure 32.
Specific conductance (mS/m) in the Ells, MacKay
Hangingstone, Steepbank and Muskeg Rivers.


Ells River
Mackay River
Hangingstone River
Steepbank River
Muskeg River
0 ice
50 depth - cm
20
0
Specific Conductance m S/m
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

In contrast to the Ells River, a distinct seasonal pattern of conductance occurred in the remaining Rivers (Figure 32). All rivers investigated displayed a summer peak which decreased to a minimum during the autumn, then under ice cover conductance increased and the overall maxima occurred.

4.3.1.4 Calcium

Calcium concentrations fluctuated least in the Ells River with only a small increase occurring during the winter (Figure 33). Again, in marked constrast, large winter peaks occurred in all the other rivers 49.5, 44.8, 43.0, 33.1 mg L^{-1} in the MacKay, Muskeg, Steepbank and Hangingstone Rivers respectively. During the summer of 1978 calcium levels in the Muskeg River fluctuated, displaying several distinct peaks (Figure 33) which coincided with periods of minimum stream discharge. In the MacKay, Steepbank, and Hangingstone, summer peaks were evident but always smaller than winter ones.

4.3.1.5 Sodium

Sodium concentrations in the Ells River remained low (3.9 mg L^{-1}) and fluctuated less than in any other river (Figure 34).

As ice formed during the fall, sodium decreased and remained uniform until after ice break-up during early May. The seasonal pattern, however, was more variable in the remaining rivers. In the Mackay, a series of distinct peaks were evident; 52.4 mg L^{-1} during August of 1978, 57.5 mg L^{-1} during March of 1979, 51.8 mg L^{-1} during September, 1979 and 55.1 mg L^{-1} during December, 1979. These peaks originated and disappeared quickly. In between values fell to minima, ranging from 7.9 to 19.5 mg L^{-1} sodium. A decreasing stepwise series of peaks from early August, 1978 until a minimum in May, 1979 were noted for the Hangingstone River.

Figure 33.
Calcium (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank, and Muskeg rivers.

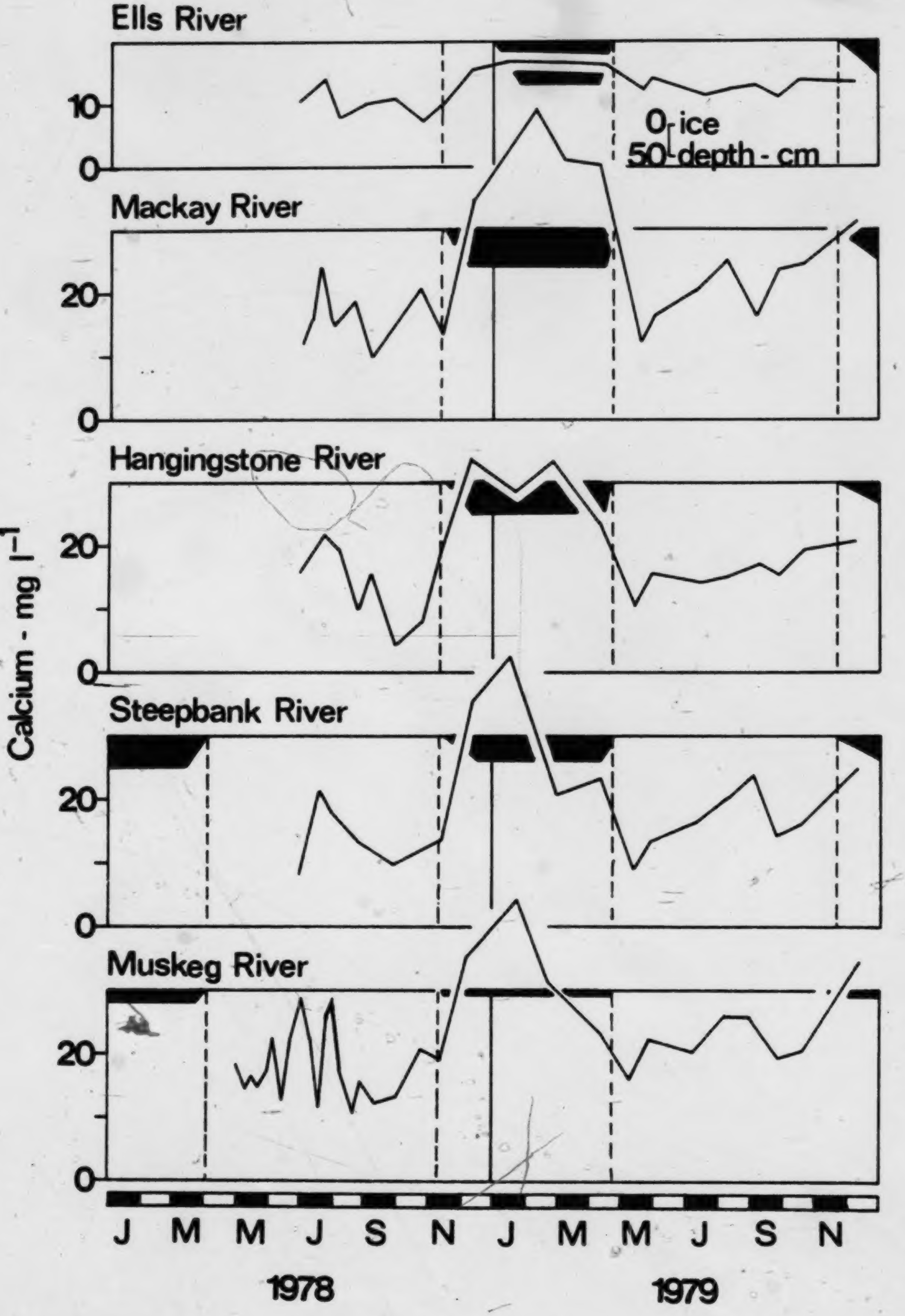
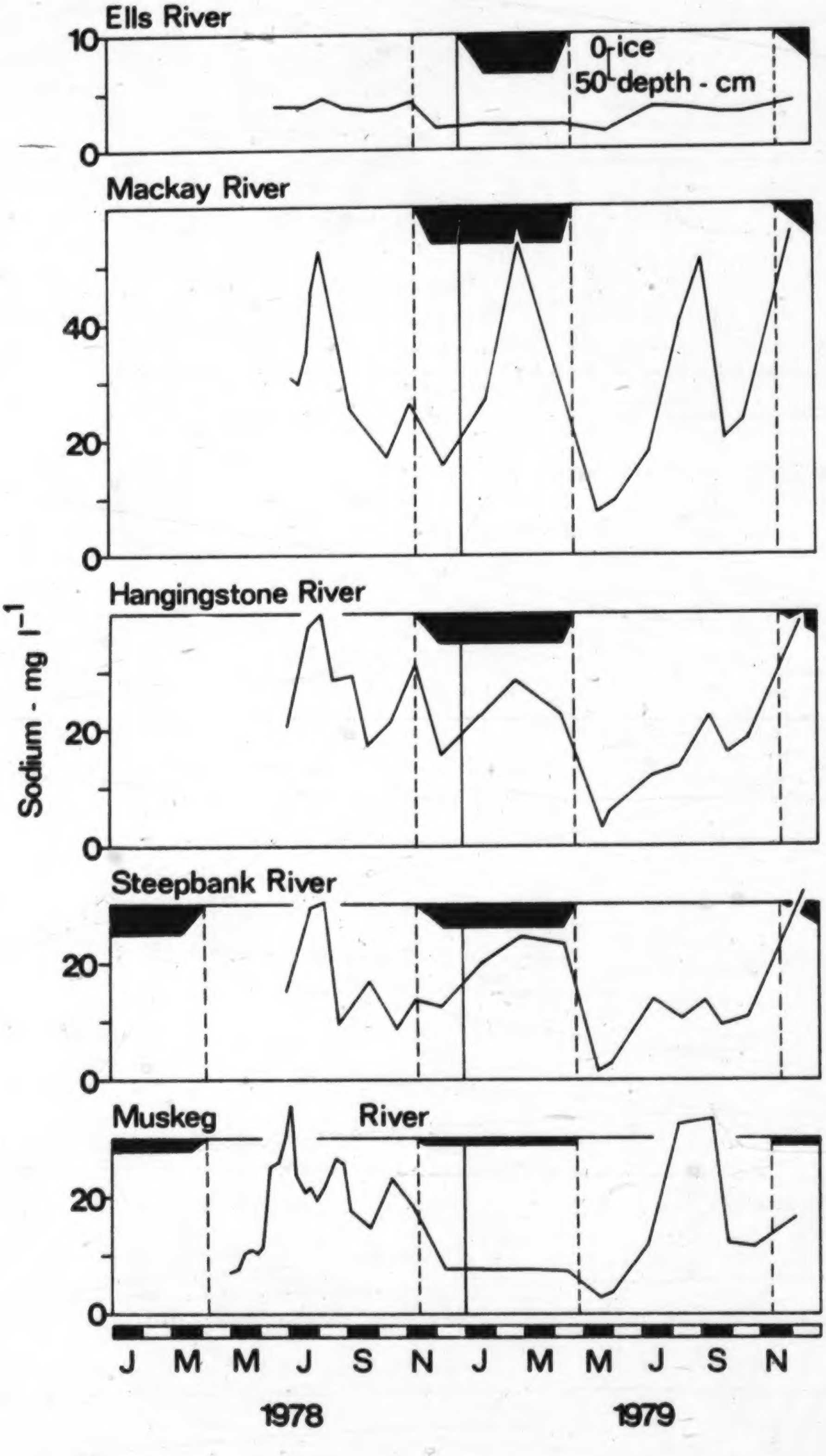

Ells River
10
0
0 ice
50 depth - cm
Mackay River
20
0
Hangingstone River
20
0
Steepbank River
20
0
Muskeg River
20
0
Calcium - mg l⁻¹
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 34.
Sodium (mg l^{-1}) in the Ells, Hnagingstone, Steepbank, and Muskeg rivers.


Ells River
10
0
0 ice
50 depth - cm
Mackay River
40
20
0
Hangingstone River
20
0
Steepbank River
20
0
Muskeg River
20
0
Sodium - mg l⁻¹
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

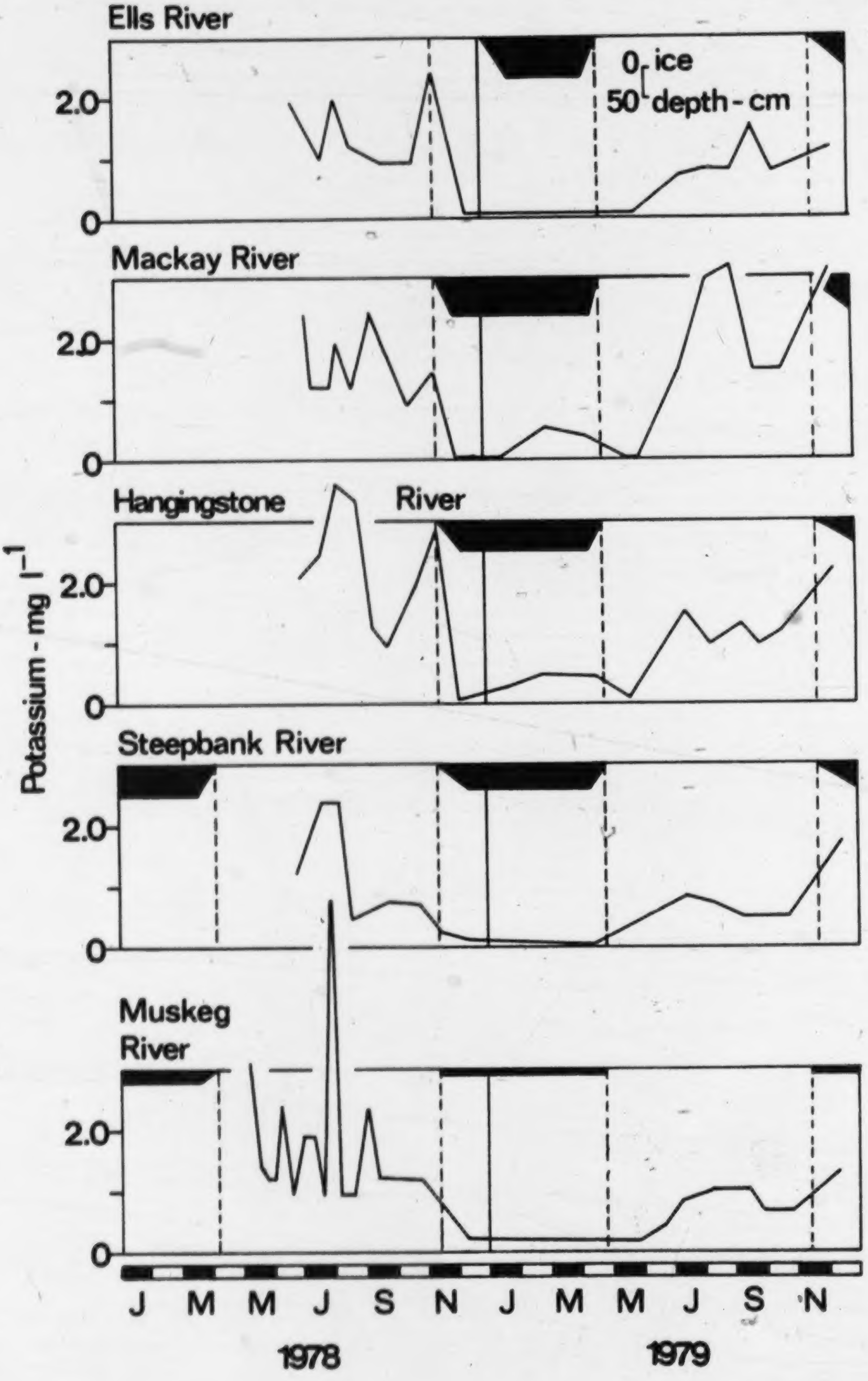
After May, sodium concentrations increased steadily, peaking again during early December at 31.2 mg L^{-1}. Sodium concentrations in the Steepbank River fluctuated similarly, but the winter peak (48.7 mg L^{-1}) was larger than the autumn one of 16.4 mg L^{-1} (Figure 34). Spring minima in the Steepbank River were also less than the spring minimum in the Hangingstone River, reaching 3.20 mg L^{-1}.

A decreasing stepwise pattern of sodium similar to the Hangingstone was also evident in the Muskeg River during July (35.6 mg L^{-1}). August (26.50 mg L^{-1}) and during October (18.70 mg L^{-1}). Unlike the MacKay, Hangingstone and Steepbank rivers, but like the Ells River, sodium levels fell after mid-October 1978 and remained low all winter with a May, 1979 minimum of 5.7 mg L^{-1}. Sodium concentrations increased to a maximum of 33.2 mg L^{-1} during September, 1979, then decreased but continued to show an upward trend during the onset of ice formation and termination of the study.

4.3.1.6 Potassium

Potassium concentrations were quite similar seasonally among the five rivers (Figure 35). Varying sized peaks occurred during the summer growth period and late autumn/early winter season. Two distinct peaks occurred in the Ells and Hangingstone Rivers during August and November (1.94 and 2.40 mg L^{-1}; 3.60 and 2.88 mg L^{-1}) respectively. One main peak occurred during July/August in the Steepbank River, whereas the potassium levels fluctuated more irregularly in the MacKay and Muskeg Rivers (Figure 35). Four peaks were discernable in the MacKay River in July, August, September, and November. Five peaks occurred in the Muskeg River during May, June/July, mid July and late August. Potassium levels were low in each river during the winter, but increased from early May minima to summer peaks, and fell to a minima.

Figure 35.
Potassium (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
0 ice
50 depth - cm
2.0
0
Mackay River
2.0
0
Hangingstone River
2.0
0
Steepbank River
2.0
0
Muskeg River
2.0
0
Potassium - mg l^{-1}
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

4.3.1.7 Magnesium

Magnesium fluctuated little in the Ells, ranging from 1.6 to 4.9 mg L^{-1} (Figure 36). Small minima occurred just prior to ice formation and immediately after ice break-up. Seasonal patterns, however, in the other five rivers were more pronounced, with small summer peaks and very large winter maxima (17.9, 15.8, 14.9 and 14.1 mg L^{-1}) in the MacKay, Steepbank, Muskeg and Hangingstone Rivers respectively. Magnesium concentrations decreased rapidly after ice break-up in early May, perhaps due to dilution associated with increased discharge attributed to the spring melting period. Nevertheless, spring minima were followed by increasing magnesium concentrations, and again, a fall minimum associated with peak discharge periods.

The concentrations of magnesium were similar seasonally for all five rivers, ranging from 6.40 mg L^{-1} in the MacKay River during 1978 to 10.3 mg L^{-1} in the Muskeg during 1979. Most irregularity occurred during 1978 in the Muskeg River (Figure 36) coincidentally with unusually high discharges during early September.

4.3.1.8 Iron

An investigation of iron concentrations indicated that the MacKay, Hangingstone, and Steepbank Rivers were similar seasonally (Figure 37). Large early winter, late winter/early spring, and autumn (1979) maxima occurred. Iron ranged from 0.18 mg L^{-1} in the Steepbank to 0.36 mg L^{-1} in the MacKay. Two large peaks occurred in the Muskeg River in early May and early December, 1979 (0.73 and 0.99 mg L^{-1} respectively), otherwise values fluctuated little. Iron concentrations remained relatively constant in the Ells River throughout the study, with only slight deviation similar to the seasonal patterns indicated for the MacKay, Hangingstone and Steepbank Rivers.

Figure 36.
Mangnesium (mg l^{-1}) in the Ells, MacKay, Hnagingstone, Steepbank and Muskeg rivers.

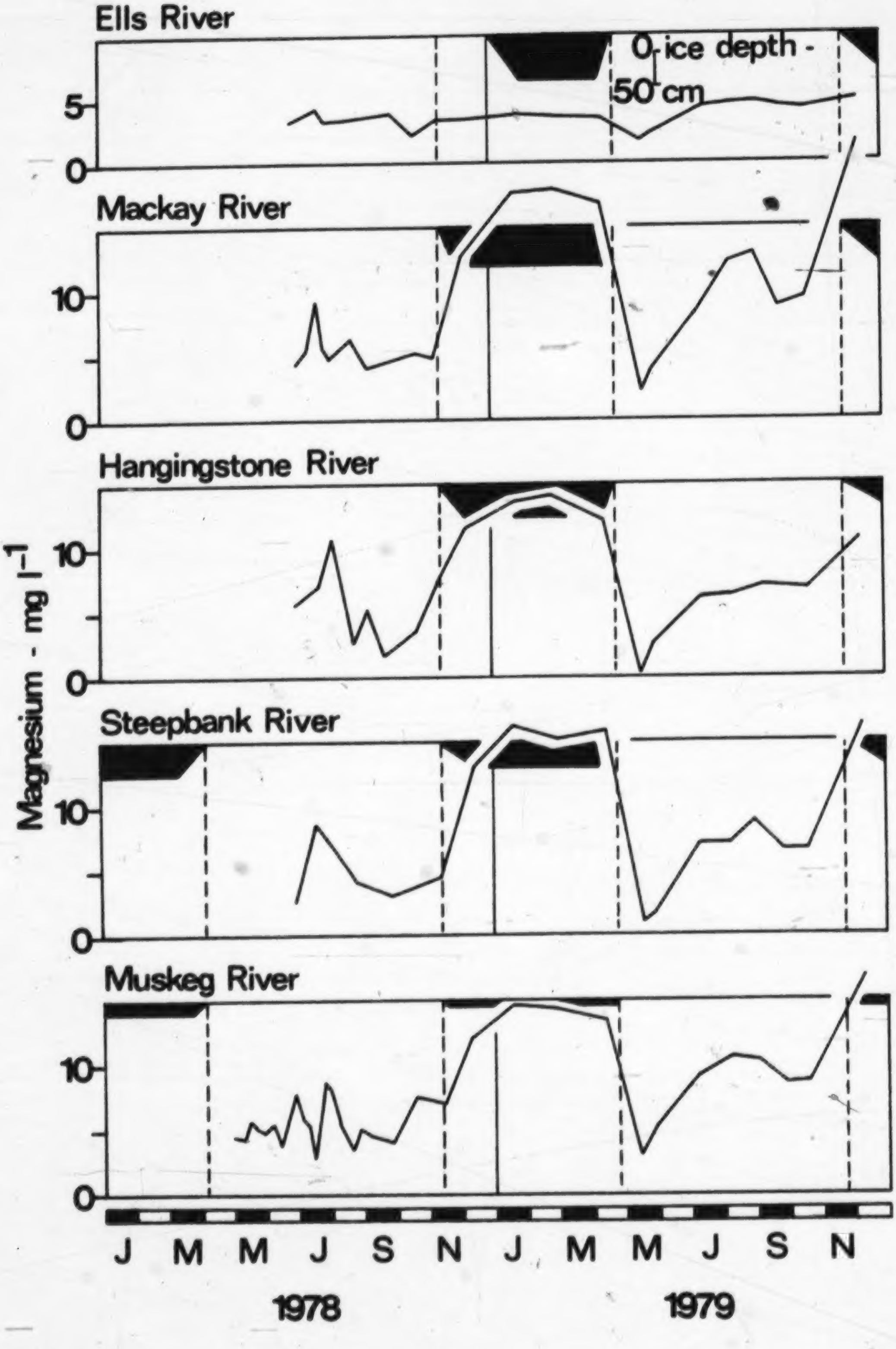
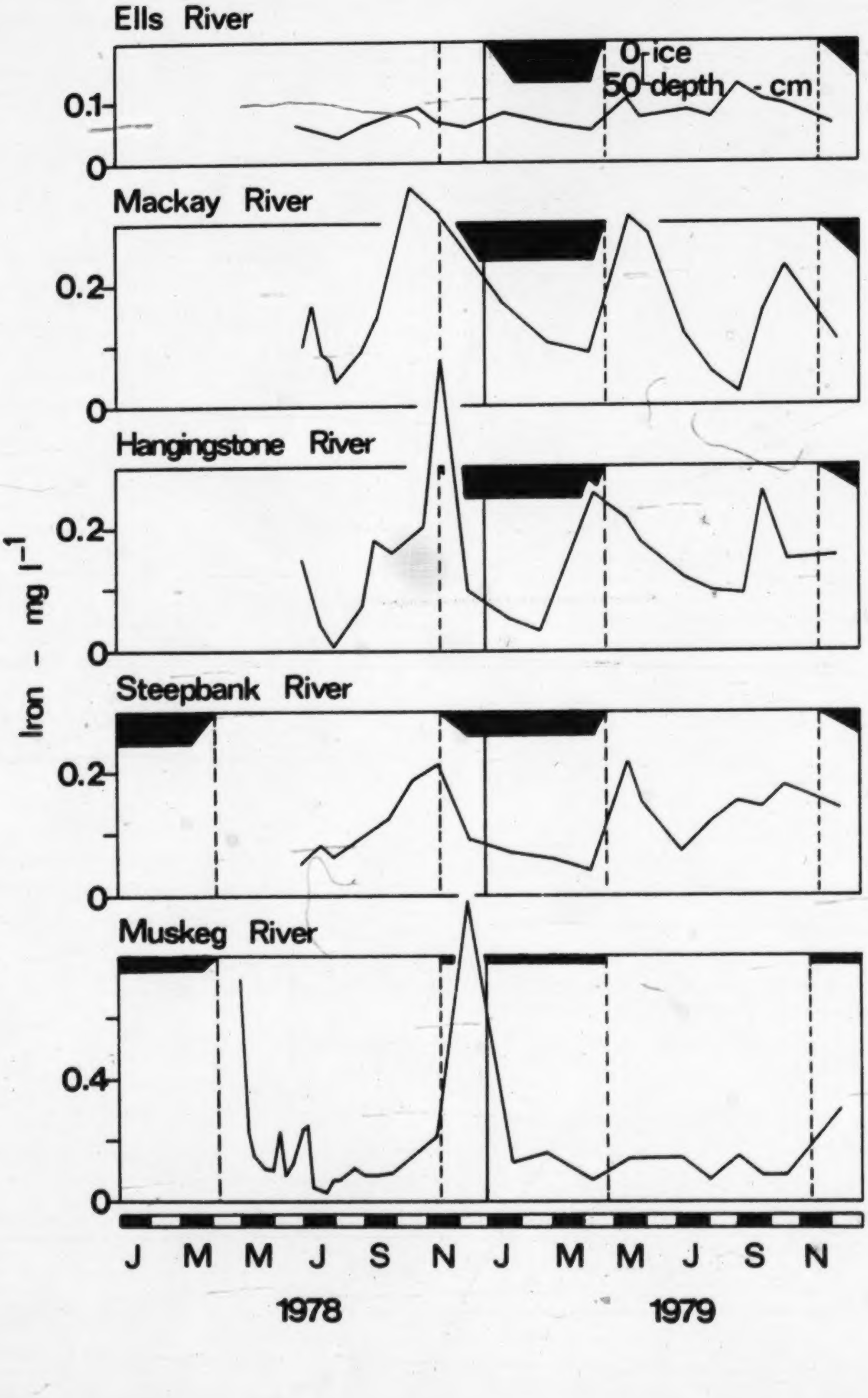

Ells River
0 ice depth -
50 cm
5
0
Mackay River
10
0
Hangingstone River
10
0
Steepbank River
10
0
Muskeg River
10
0
Magnesium - mg l^-1
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 37.
Iron (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
0-ice
50-depth - cm
0.1
0
Mackay River
0.2
0
Hangingstone River
0.2
0
Steepbank River
0.2
0
Muskeg River
0.4
0
Iron - mg l⁻¹
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

4.3.1.9 Manganese

Manganese levels fluctuated irregularly in the Muskeg River, particularly during 1978 (Figure 38). In this river two winter maxima of 0.04 and 0.05 mg L^{-1} declined during ice-out to fluctuate throughout the open water period. One winter peak occurred in the Steepbank River (0.05 mg L^{-1}), while a minimum manganese concentration appeared during late winter, and in contrast to the Muskeg River, the levels increased quickly after ice-out and again in early August.

Manganese levels fluctuated irregularly in the Hangingstone River with peaks of 0.075 and 0.095 mg L^{-1} during the winter season. Fewer rapid and irregular fluctuations occurred in the MacKay River (Figure 38). Here the seasonal pattern was dominated by an autumn and a smaller winter maxima (0.051 and 0.013 mg L^{-1} respectively). Ells River manganese levels decreased from June (0.01 mg L^{-1}) to an overall November minimum of 0.007 mg L^{-1} during 1978. During 1979, however, manganese concentrations increased irregularly to peak during September, 0.101 mg L^{-1} (Figure 38).

4.3.1.10 Sulphate

Sulphate seasonal patterns were similar for the MacKay, Hangingstone and Steepbank Rivers (Figure 39). The concentrations per river, however, were very different. Sulphate ranged from a minimum of 0.0 mg L^{-1} in the Muskeg River to a maximum of 53 mg L^{-1} in the MacKay River.

Small summer peaks of sulphate occurred each year in the MacKay, Hangingstone and Steepbank Rivers (i.e. 53.0, 23.5, 13.4 mg L^{-1} respectively). Peaks were far less pronounced in the Ells River, fluctuating between 4.4 and 9.0 mg L^{-1} (Figure 39). However, in the

Figure 38.
Manganese (mg l^{-1}) in the Ells, MacKay, Hnagingstone, Steepbank and Muskeg rivers.

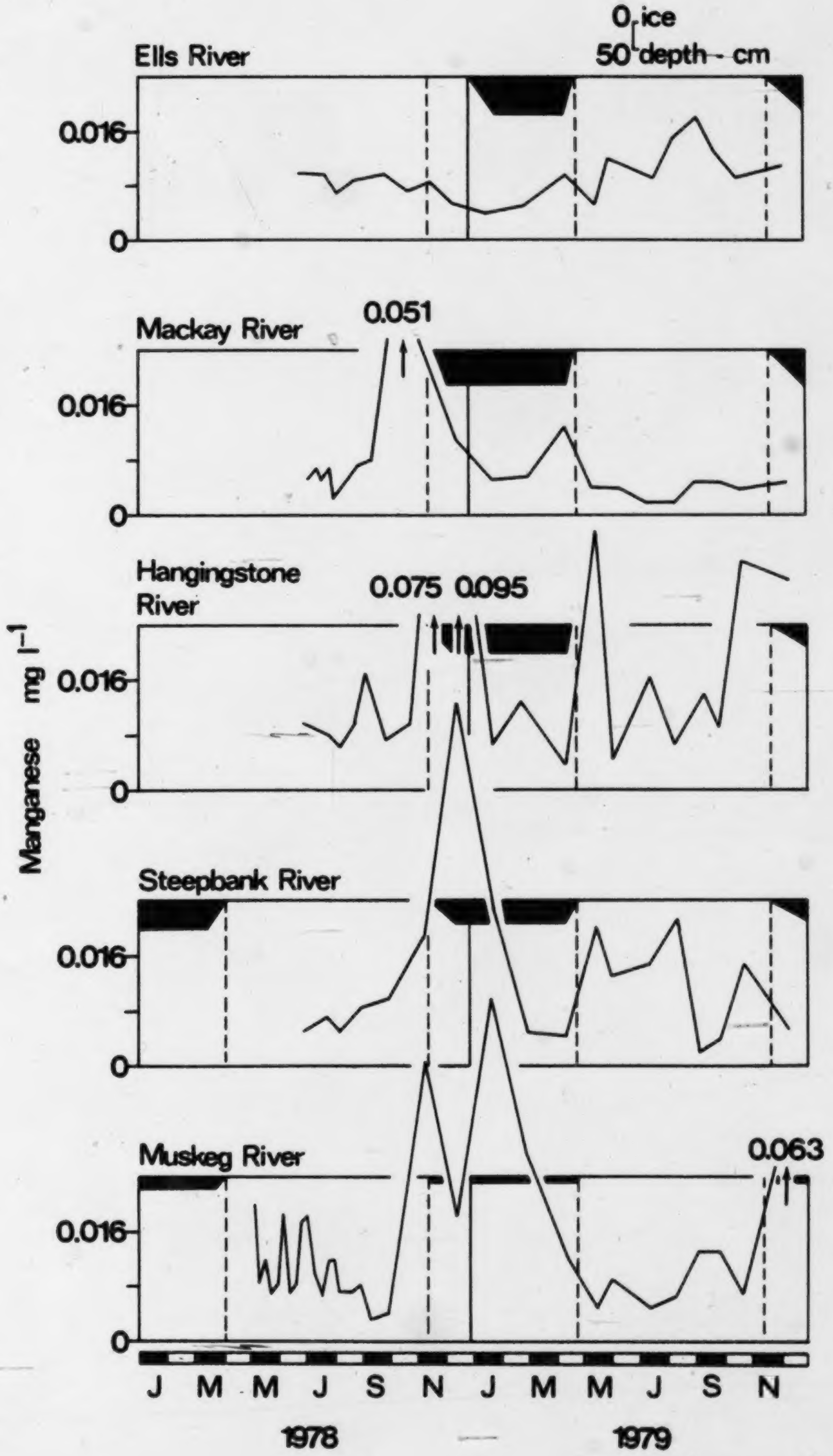
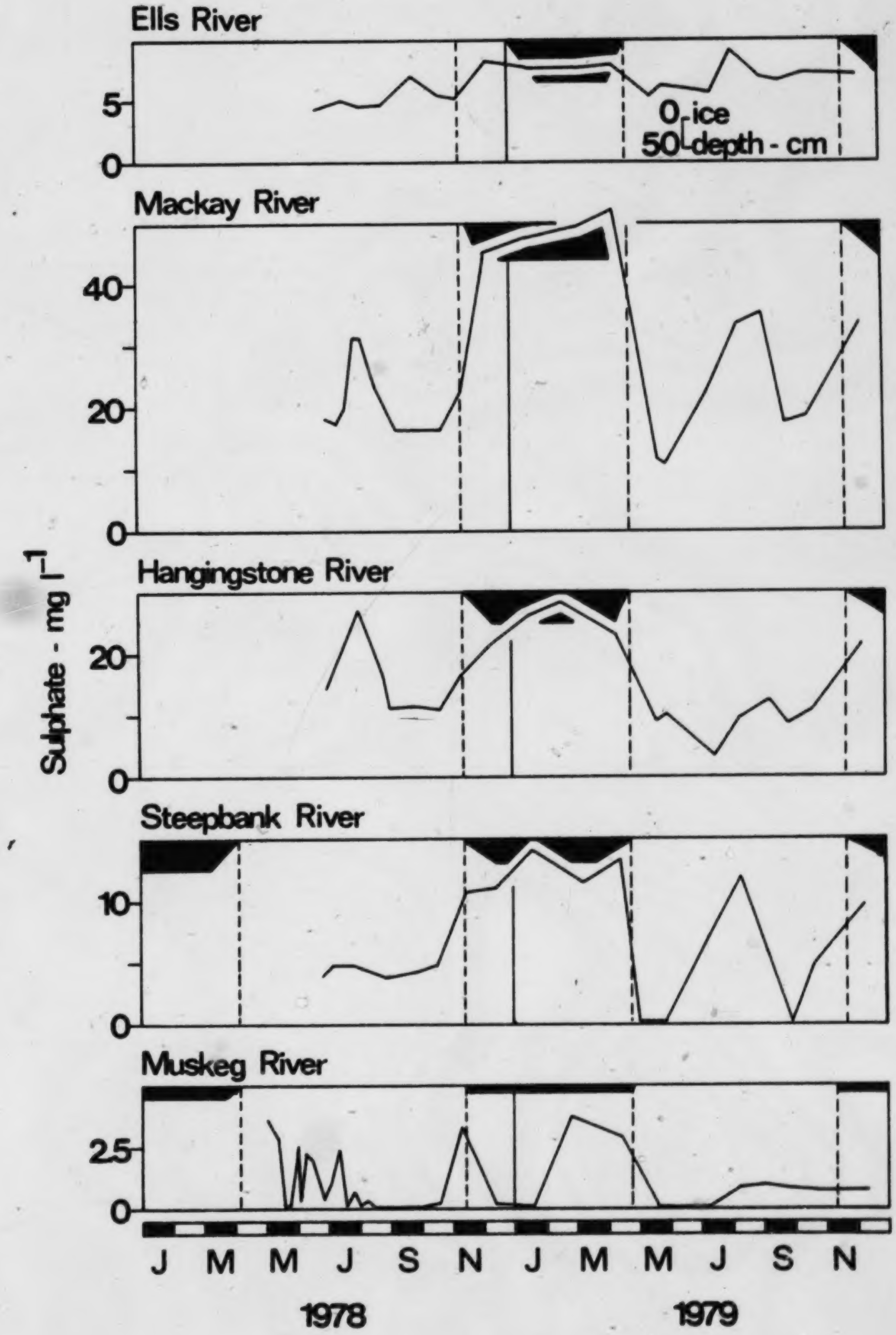

0 ice
50 depth - cm
Ells River
0.016
0
Mackay River
0.051
Hangingstone River
0.075
0.095
Steepbank River
Muskeg River
0.063
Manganese mg l⁻¹
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 39.
Sulphate (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
5
0
0 ice
50 depth - cm
Mackay River
40
20
0
Hangingstone River
20
0
Steepbank River
10
0
Muskeg River
2.5
0
Sulphate - mg l^{-1}
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Muskeg River, sulphate levels fluctuated widely during 1978, particularly during the open water period May to August. Winter peaks also occurred in the Muskeg River; one in November (3.3 mg L^{-1}) and the other in February (3.75 mg L^{-1}) Figure 39.

4.3.1.11 Chloride

Chloride was undetectable in the Ells River. Seasonal patterns were, however, similar in the MacKay, Hangingstone and Steepbank Rivers with large winter maximums and a smaller summer peak (Figure 40). Peak values of 20.0, 30.0 and 8.0 mg L^{-1} were found in these three rivers respectively. Seasonal patterns were similar in the Muskeg River; however, summer rather than winter maximum occurred, and fluctuations were more frequent during 1978 than during 1979. Two peaks of 35.6 and 25.0 mg L^{-1} occurred during June and July of 1978, and of 27.5 and 42.5 mg L^{-1} during August and September of 1979.

4.3.1.12 Nitrate-nitrogen

Distinct seasonal nitrate-nitrogen fluctuations did not occur in the Ells River (Figure 41). More distinctive patterns occurred in the other four rivers (Figure 41), where the concentrations of nitrate-nitrogen were low during mid-summer, rising to autumn/early winter peaks. Then, as ice formed it declined in all but the Muskeg Rivers. The greatest variability occurred in the Muskeg River during 1978 (Figure 41).

4.3.1.13 Phosphate-phosphorus

Phosphate-phosphorus concentrations fluctuated widely and irregularly in the Ells River. Four major peaks occurred in late August (0.15 mg L^{-1}), early December (0.24 mg L^{-1}), and mid-January, 1979 (0.26 mg L^{-1}) and mid-May (0.29 mg L^{-1}), (Figure 42). Low summer phosphate-

Figure 40.
Chloride (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.

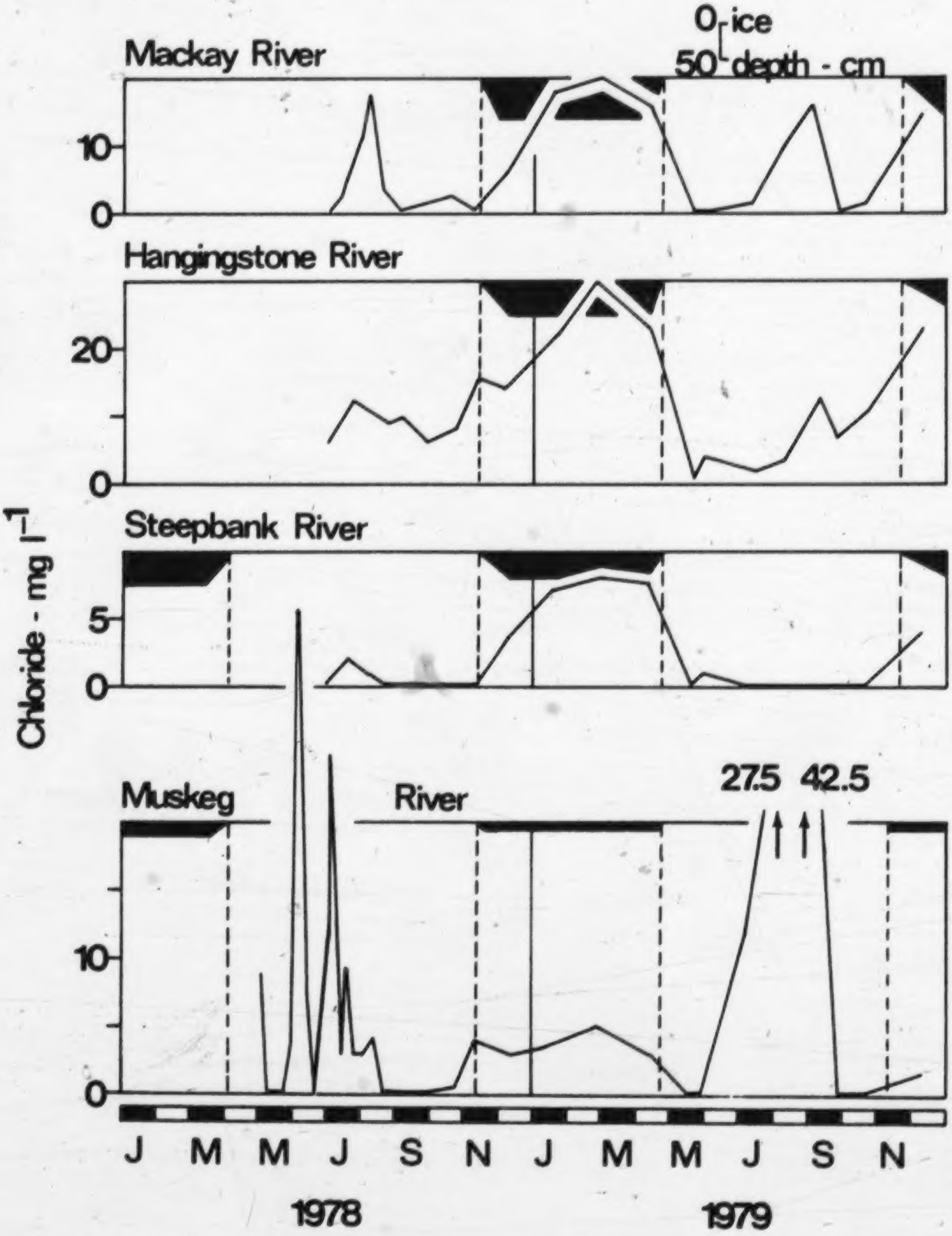

0 ice
50 depth - cm
Mackay River
10
0
Hangingstone River
20
0
Steepbank River
5
0
Chloride - mg l-1
Muskeg River
27.5
42.5
10
0
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 41.
Nitrate-Nitrogen (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank, and Muskeg rivers.

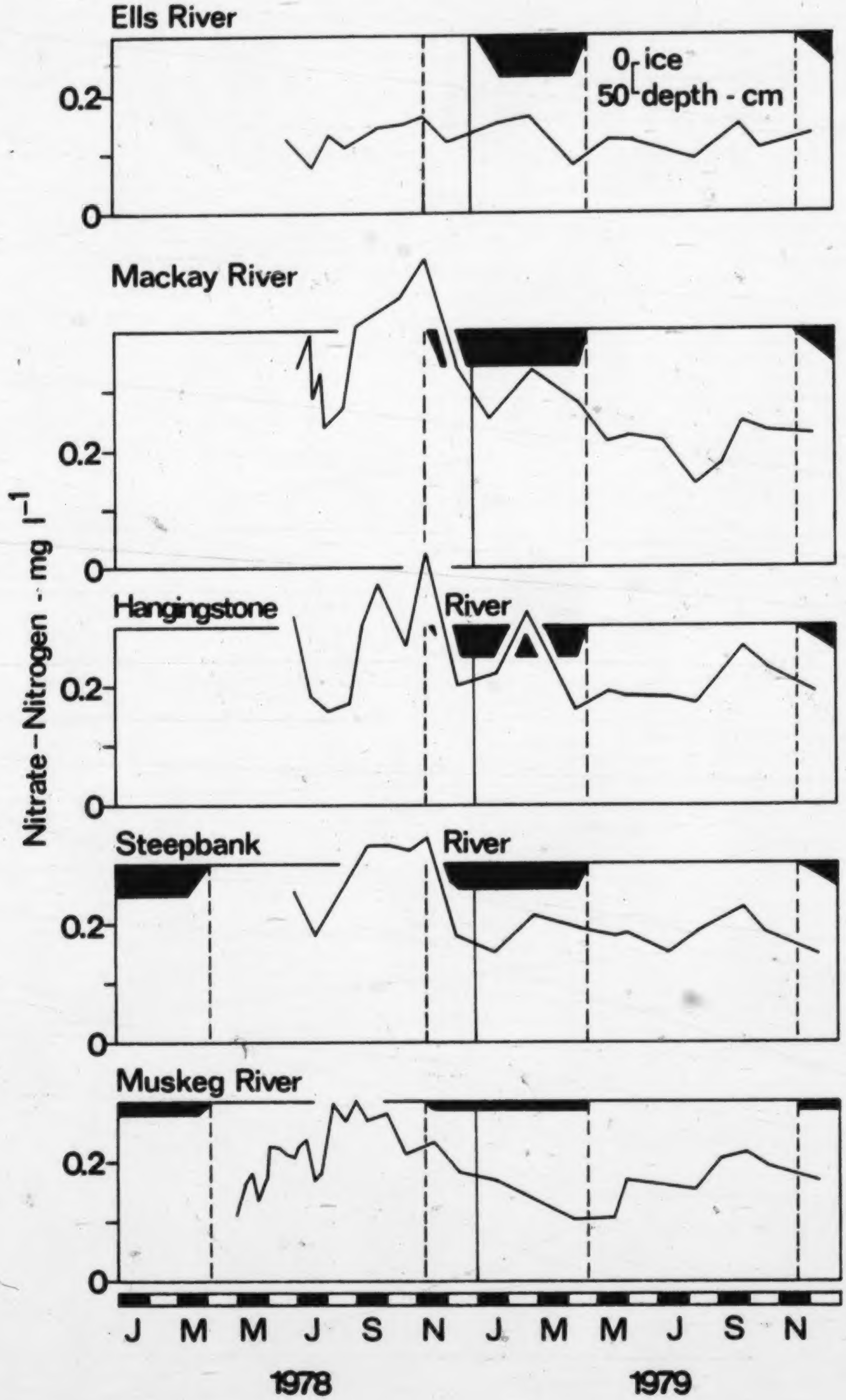
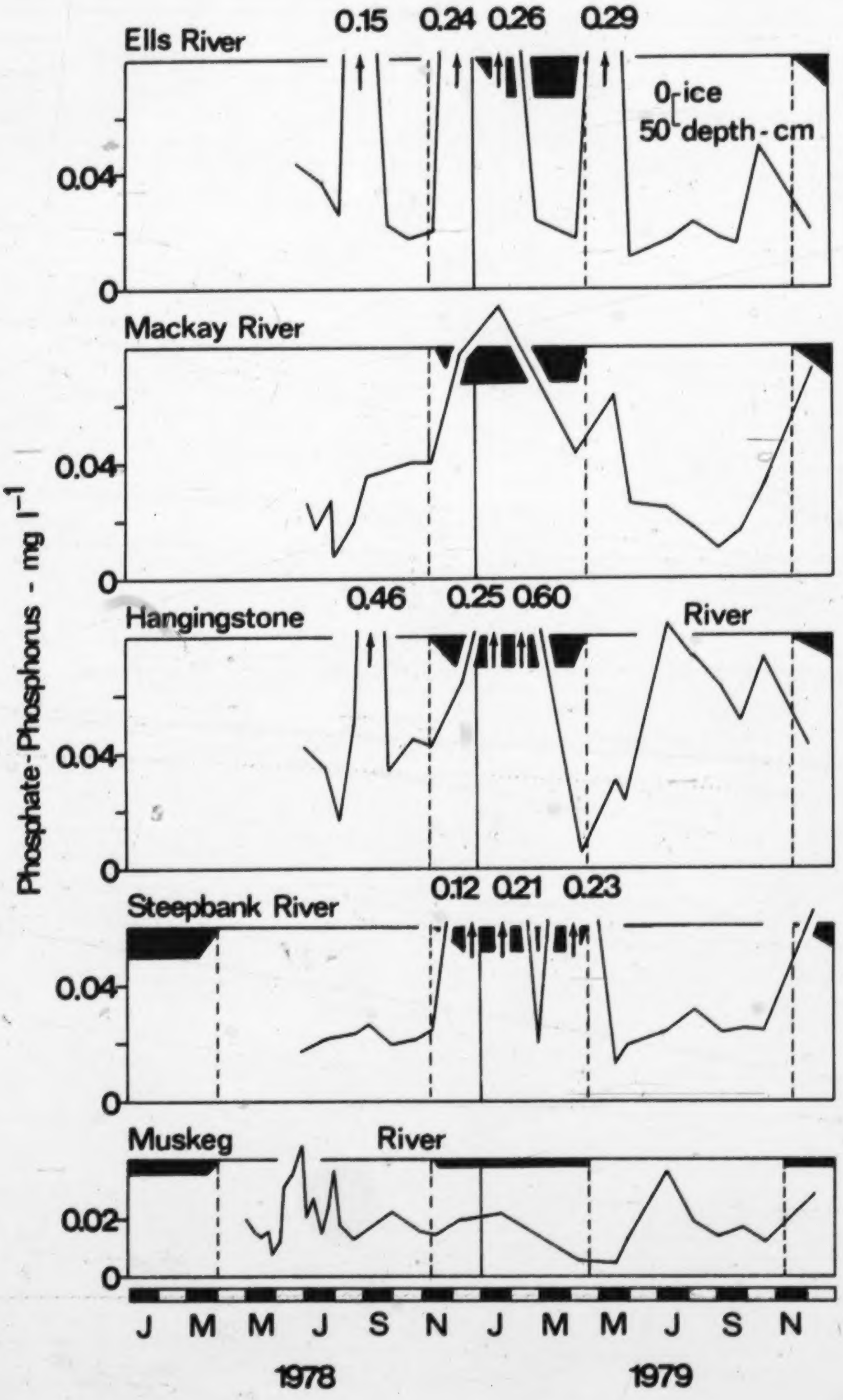

Ells River
Mackay River
Hangingstone River
Steepbank River
Muskeg River
0.2
0
0 ice
50 depth - cm
Nitrate - Nitrogen - mg l⁻¹
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 42.
Phosphate-Phosphorus (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
0.15
0.24
0.26
0.29
0 ice
50 depth - cm
Mackay River
Hangingstone River
0.46
0.25
0.60
Steepbank River
0.12
0.21
0.23
Muskeg River
0.04
0.02
0
Phosphate-Phosphorus - mg l^{-1}
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

phosphorus values increasing to a mid-winter maximum of 0.094 mg L^{-1} occurred in the MacKay River. Large winter maxima occurred in the Hangingstone and Steepbank Rivers. In both a minimum occurred in May, however, this was followed by a dramatic increase to 0.084 mg L^{-1} during mid-July in the Hangingstone River only. The overall Hangingstone maximum was 0.60 mg L^{-1} and the Steepbank maximum was 0.23 mg L^{-1} also during the winter of 1979.

4.3.1.14 Dissolved silica

Dissolved silica fluctuations were quite similar in all but the Ells River (Figure 43). In the Ells, dissolved silica fluctuated the least with only slight fall peaks occurring. In the other rivers it increased to a winter maximum then declined with the onset of spring. (Figure 43). While mean dissolved silica levels were lower in the MacKay River than the Muskeg, Steepbank and Hangingstone rivers, the dissolved silica content of the Ells River was three times lower again. Despite the numerous differences concerning dissolved silica concentration the trend toward higher winter concentration was evident.

4.3.1.15 pH and alkalinity

In all rivers, pH varied from being acid to basic with maximum and minimum values occurring during the summer and winter months respectively (Figure 44). In the Ells River, pH ranged from 6.0 to 9.0 and this range was the widest among the five rivers.

Alkalinity was maximum in all but the Ells River during the winter period. Small peaks of alkalinity occurred during the early summer, in the five rivers (Figure 45). Alkalinity ranged from .80 meq L^{-1} in the Ells to a maxium of 5.3 meq L^{-1} in the Steepbank River.

Figure 43.
Dissolved Silica (mg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.

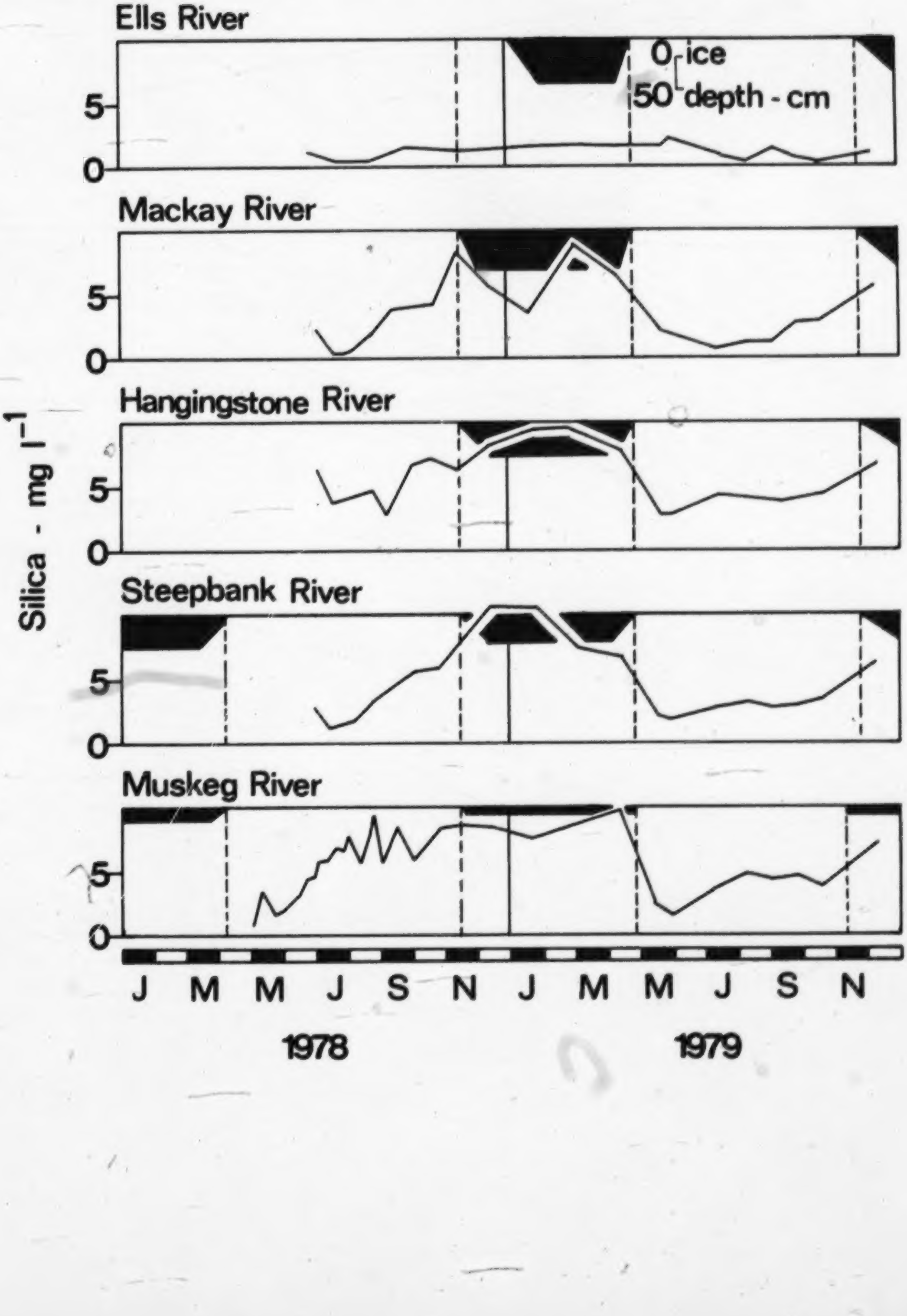

Ells River
Mackay River
Hangingstone River
Steepbank River
Muskeg River
0 ice
50 depth - cm
Silica - mg l^{-1}
5
0
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 44.
pH in the Ells, MacKay, Hangingstone,
Steepbank and Muskeg rivers.

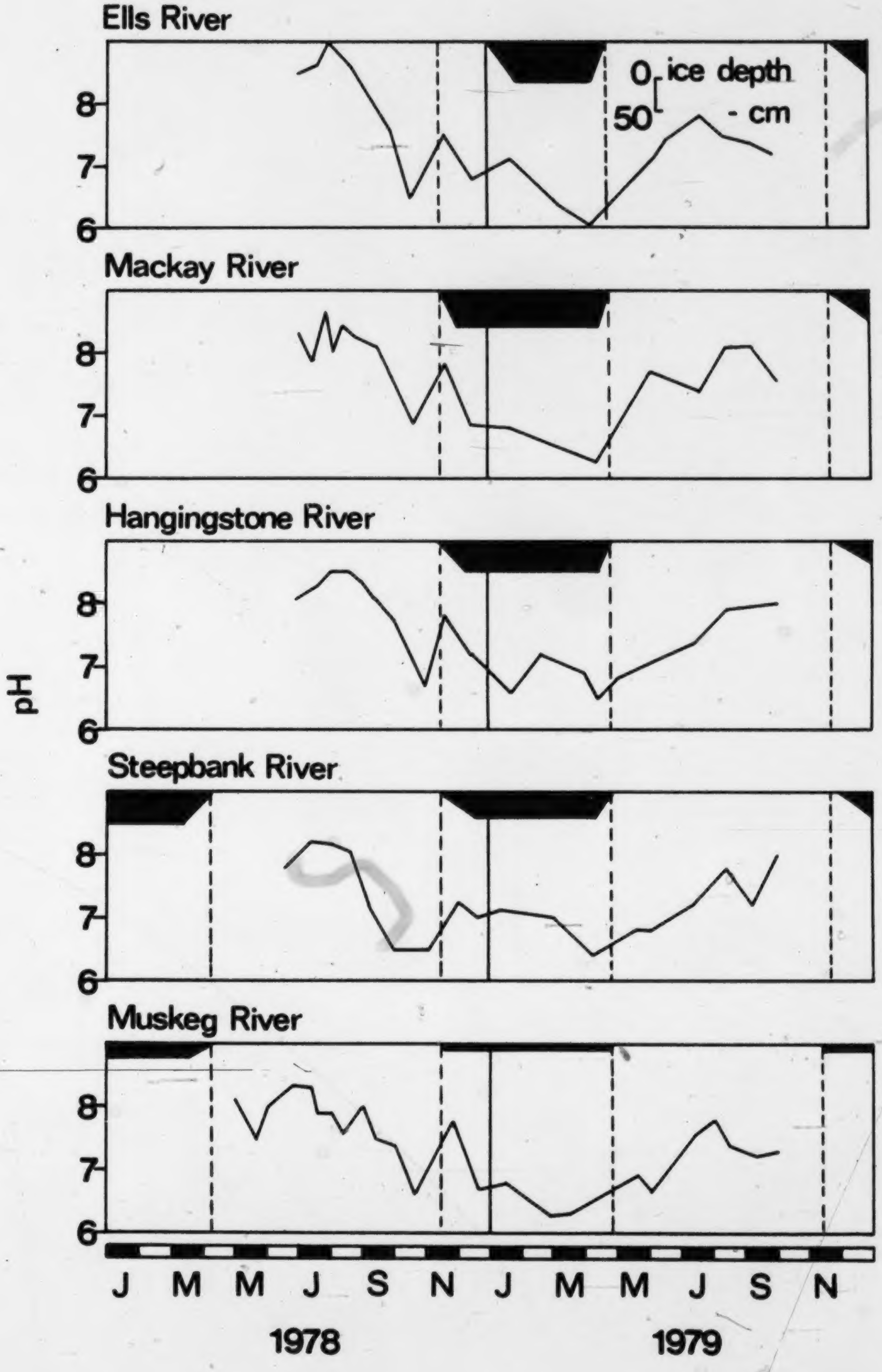
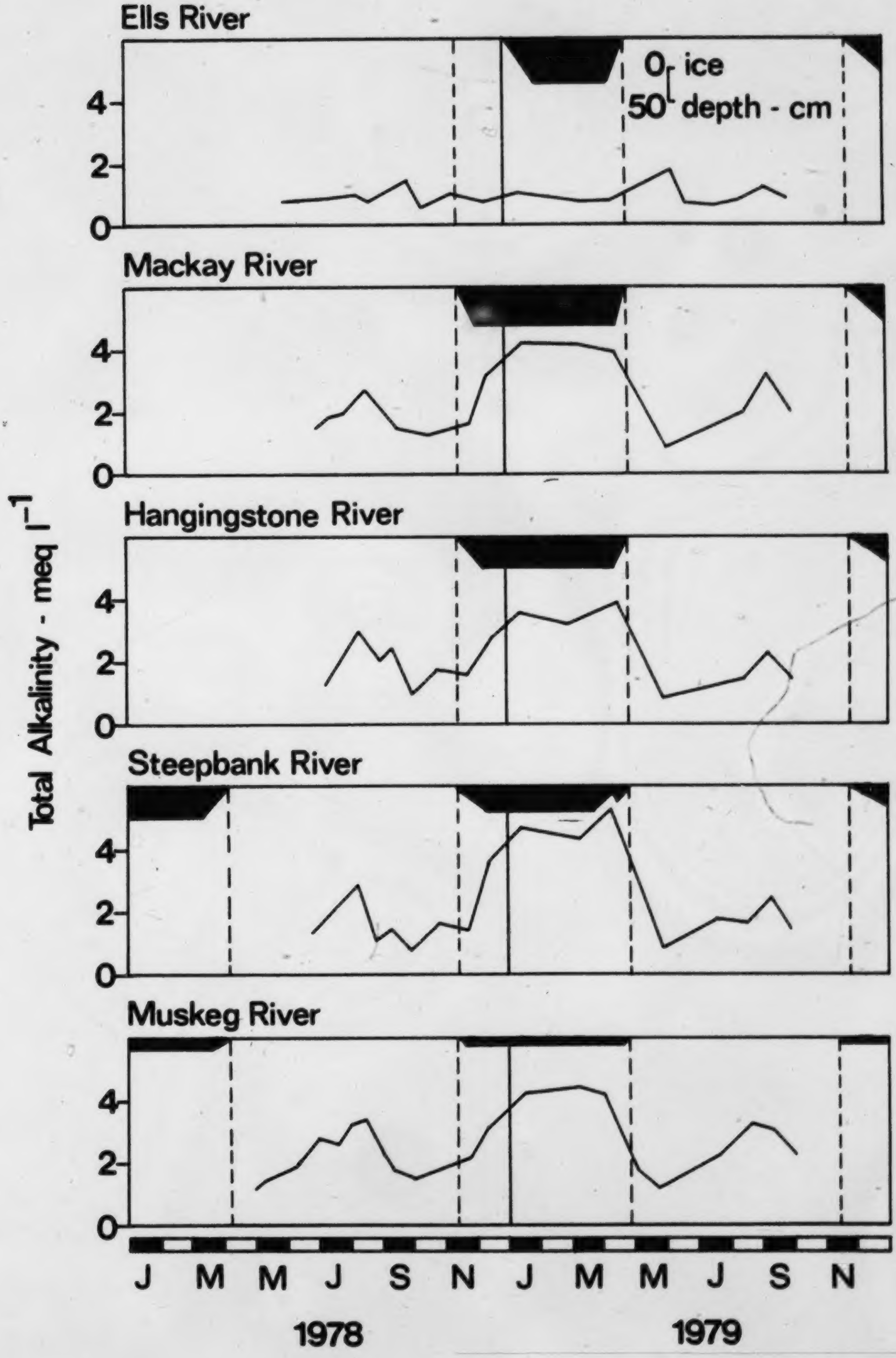

Ells River
0 ice depth
50 - cm
Mackay River
Hangingstone River
Steepbank River
Muskeg River
pH
8
7
6
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 45.
Total Alkalinity (meg l^{-1}) in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
Mackay River
Hangingstone River
Steepbank River
Muskeg River
0 ice
50 depth - cm
Total Alkalinity - meq l^{-1}
0
2
4
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

4.3.2 Temporal Epilithic Algal Changes

4.3.2.1 Species Composition and Cell Numbers

4.3.2.1.1 Species Composition

Algae from four divisions dominated the epilithon in all five rivers. These were the Cyanophyta (blue-green algae), Chlorophyta (green algae), Bacillariophyta (diatoms), and Rhodophyta (red algae). A list of all the species encountered is presented in Table 18. Also indicated is whether they were found freely suspended in the river water (phytoplankton).

In the Muskeg River, Cyanophycean algae dominated with two species, *Lyngbya aerugineo-caerulea* and *Phormidium* sp., being the most important (Figure 46 and 47). During July 1978 this division accounted for more than 90% of the total epilithic community, decreasing to 53% by late August. Two other Cyanophycean algae, *Calothrix breviarticulata* and *C. braunii*, also contributed significantly at times (Figure 46). However, these species appeared to be more specific with respect to their ecological requirements. Diatoms were more prevalent during May and August through October 1978. *Synedra ulna* and *Nitzschia fonticola* were important during May and these, together with *Gomphonema olivaceum* and *Synedra rumpens*, during the fall period. During 1978, Chlorophycean algae were less important than the two divisions mentioned earlier, however, during September they accounted for 15.3% of the total community when *Draparnaldia glomerata* was present. Rhodophycean algae, *Batrachospermum vagum* and *Audouinella violaceae*, were also present, contributing significantly only during May, July and November of 1978. The former species was most prevalent in May and November, and the latter during July.

Table 18. The complete list of algal species encountered in the five rivers (M = Muskeg River; SB = Steepbank River; HS = Hangingstone River; MK = MacKay River; E = Ells River). (+ = present; - = absent;   = phytoplankton).

	M	SB	HS	MK	E
CYANOPHYTA					
Anabaena affinis Lemm.	+	+	+	+	+
A. inaequalis Borge	-	+	-	-	-
A variabilis Kütz.	+	+	+	+	+
A. wisconsinense Prescott	+	-	-	-	-
Aphanizomenon flos-aquae (L.) Ralfs.	+	-	-	-	-
Calothrix braunii Bornet & Flahault	+	+	+	+	+
C. breviarticulata West & West	+	+	-	-	-
C. fusca (Kütz.) Bornet & Flahault	+	-	-	-	-
Chamaesiphon incrustans Grunn.	+	+	-	-	-
Chroococcus limneticus Lemm.	+	+	-	+	-
Fischerella muscicola (Borzi) Gomont	-	+	-	-	-
Gomphosphaeria aponina Kütz	-	-	-	+	-
G. lacustris v. *compacta* Lemm.	+	-	-	-	-
Lyngbya aerugineo-caerulea (Kutz.) Gomont	+	+	+	+	+
L. aestuarii (Mert.) Lieb.	-	+	-	-	-
L. epiphytica Hieronymus	+	+	-	-	-
L. nordgaardii Wille	+	+	-	-	-
L. taylorii Drouet & Strickland	+	+	-	-	-
L. versicolor (Watt.) Gomont	+	+	-	-	-
Merismopedia elegans A. Braun	+	-	-	-	-
M. glauca (Ehr.) Naegeli	+	-	-	+	-
Microcoleus vaginatus (Vauch.) Gomont	-	+	-	-	-
Microcystis aeruginosa Kütz. emend Elenkin	+	+	-	-	-
Nostoc commune Vaucher	+	+	+	+	+
N. microscopicum Carmichael	+	+	+	+	+
N. verrusosum Vaucher	+	+	+	+	+
Nostoc sp.	+	+	+	+	+
Oscillatoria amphibia C.A. Agardh.	-	-	-	+	-
O. lacustris (Kleb.) Geitler	+	+	-	-	-

Table 18. Continued.

	M	SB	HS	MK	E
O. tenuis C.A. Agardh.	+	+	-	-	-
Oscillatoria sp.	+	+	-	-	+
Phormidium favosum (Bory) Gomont	+	+	-	-	-
P. tenue (Menegh.) Gomont	+	+	-	-	-
Rhaphidiopsis sp.	-	-	-	-	±
Rivularia haematites (D.C.) C.A. Agardh.	+	+	-	-	-
Schizothrix tinctoria Gomont	+	+	-	-	-
Tolypothrix distorta Kütz.	-	+	-	-	-
CHLOROPHYTA					
Ankistrodesmus falcatus (Corda) Ralfs.	±	±	±	±	±
A. spiralis (Turner) Lemm.	±	-	-	-	-
C. globosa Snow	-	-	-	+	-
Chaetophora incrassata (Hud.) Hazen	+	+	-	-	-
Chlamydomonas sp.	+	+	+	+	+
Cladophora glomerata (L.) Kütz.	+	+	+	+	+
Chlorella ellipsoidea Gerneck	-	-	-	+	-
C. vulgaris Beyer	+	+	+	+	+
Closterium sp.	+	±	±	±	±
Coelastrum scabrum Reinsch	+	-	-	+	-
Coleochaete divergens Pringscheim	+	-	-	-	-
Cosmarium sp.	±	±	-	±	-
Crucigenia quadrata Morren	+	-	-	-	-
C. tetrapedia (Kirch.) West & West	-	+	-	-	-
Dictyosphaerium ehrenbergianum Naegeli	+	±	-	-	-
D. pulchellum Wood	+	±	-	-	±
Draparnaldia acuta (C.A.Ag.) Kütz.	+	-	-	-	-
D. glomerata (Vauch.) C.A. Ag.	+	+	-	-	-
Elaktothrix sp.	-	+	-	-	-
Gloeocystis gigas (Kutz.) Lager	-	-	-	+	-
Hyalotheca sp.	-	+	-	-	-
Mougeotia sp.	+	+	-	-	+

Table 18. Continued.

	M	SB	HS	MK	E
Microspora loefgrenii (Nordst.) Lager	-	+	-	+	-
M. pachyderma (Wille) Lager	-	-	-	-	+
Oedogonium sp.	+	+	+	-	+
Pediastrum biradiatum Meyer	-	+	-	-	-
P. biradiatum v. emarginatum f. convexum Prescott	-	-	-	+	-
P. boryanum (Turp.) Meneghini	-	-	-	-	+
Pithophora varia Wile	+	+	-	-	-
Pleurotaenium spp.	-	-	+	-	-
Rhizoclonium hieroglyphicum (C.A. Ag.) Kütz.	+	+	-	-	-
Scenedesmus acutiformis Schroeder	-	-	-	+	-
S. bijuga (Turp.) Lager	+	-	-	+	-
S. dimorphus (Turp.) Kütz.	-	-	-	-	+
S. obliguus (Turp.) Kütz.	+	+	-	+	-
S. quadricauda (Turp.)de Breb.	-	-	-	+	-
Sorastrum spinulosum Naegeli	-	-	-	+	-
Sphaerocystis schroeteri Chodat	-	-	-	+	-
Sphaeroplea annulina (Roth.) C.A. Agardh.	-	-	-	+	-
Spirogyra sp.	+	+	-	+	-
Stigeoclonium sp.	+	+	+	+	+
S. pachyderm Prescott	+	+	-	-	-
Staurastrum sp.	-	+	+	-	-
Tetraedron asymmetricum Prescott	-	+	-	-	-
Ulothrix sp.	+	+	+	+	+
U. subconstricta G.S. West	+	+	-	-	-
U. subtilissima Rabenhorst	-	+	-	-	-
U. zonata (Weber & Mohr) Kütz.	+	+	-	-	-
Zygnema sp.	+	-	-	-	-
RHODOPHYTA					
Batrachospermum vagum (Roth.) C.A. Agardh.	+	+	-	-	-
Audouinella violacea (Kütz.) Hamel	+	+	-	-	-

Table 18. Continued.

	M	SB	HS	MK	E
A. Pygmaea Kütz.	+	+	-	-	-
EUGLENOPHYTA					
Phacus sp.	-	+	-	-	-
CHRYSOPHYTA					
Dinobryon sertularia Ehr.	-	-	-	+	-
Mallomonas caudata Iwanoff	+	+	+	+	+
CRYPTOPHYTA					
Cryptomonas erosa Ehr.	+	+	-	-	-
C. ovata Ehr.	+	+	-	-	-
BACILLARIOPHYTA					
Achnanthes lanceolata Breb.	+	+	+	+	+
A. lanceolata v. *rostrata* Hust.	+	+	+	+	+
A. minutissima Kütz.	+	+	+	+	+
A. peragallii Brun & Herbaud	-	-	-	+	+
Amphipleura lindheimeri Grun	-	-	-	+	+
A. pellucida Kütz.	+	+	+	+	+
Amphora ovalis Kütz.	+	+	-	-	+
A. perpusilla Grun.	-	-	-	-	+
Asterionella formosa Hass.	+	+	-	-	+
Caloneis alpestris (Grun.) Cl.	+	-	-	-	-
Cocconeis pediculus Ehr.	+	+	+	+	+
C. placentula Ehr.	+	+	+	+	+
C. placentula v. *euglypta* (Ehr.) Cl.	+	+	-	-	-
Cyclotella catenata Brun.	-	-	+	-	-
C. comta (Ehr.) Kütz.	-	+	-	+	+
C. kutzingiana Thwaites	-	-	+	-	-
C. meneghiniana Kütz.	+	+	+	+	+
Cymatopleura solea (Breb.) W.Sm.	+	-	+	-	+

Table 18. Continued.

	M	SB	HS	MK	E
Cymbella amphioxys (Kütz.) Grun.	[illegible]	-	-	-	+
C. cistula (Hemprich) Grun.	+	+	+	-	+
C. lanceolata (Ehr.) V.H.	-	-	-	+	-
C. naviculiformis Auerswald	+	-	-	-	+
C. prostrata (Berkeley) Cl.	+	+	+	-	+
C. sinuata Greg.	+	+	+	-	+
C. tumida (Breb.) V.H.	-	-	+	-	+
C. turgida (Greg.) Cl.	+	-	-	-	+
C. ventricosa Kütz.	+	+	+	+	+
Diatoma elongatum Agardh.	+	+	+	+	+
D. anceps (Ehr.) Grunn.	+	-	-	-	-
D. vulgare Bory	+	+	+	+	+
D. vulgare v. *grandis* (Smith) Grun.	+	+	+	+	+
D. vulgare v. *ovalis* (Fricke) Hust.	-	-	-	-	+
D. vulgare v. *producta* Grun.	-	-	-	+	+
Epithemia argus Kütz.	+	-	-	-	-
E. sorex Kütz.	+	+	+	+	+
E. turgida (Ehr.) Kütz.	+	+	-	-	-
E. turgida v. *granulata* (Ehr.) Grun.	+	+	+	+	+
E. zebra (Ehr.) Kütz.	-	+	-	-	-
Eunotia Zunaris (Ehr.) Grun.	+	-	-	-	-
E. pectinalis v. *minor* (Kütz.) Rabh.	-	-	-	+	-
E. valida Hust.	-	-	-	+	-
Fragilaria capucina Desm.	+	+	+	-	+
F. capucina v. *acuta* Grun.	-	-	-	-	+
F. capucina v. *Lanceolata* Grun.	-	-	-	-	+
F. construens (Ehr.) Grun.	+	+	+	-	+
F. construens v. *venter* (Ehr.) Grun.	+	+	+	+	+
F. crotonensis Kitton	-	+	+	-	-
F. leptostauron (Ehr.) Hust.	-	-	-	-	+
F. pinnata Ehr.	-	-	+	-	+
F. vaucheriae (Kütz.) Boye Pet.	-	+	+	-	+

Table 18. Continued.

	M	SB	HS	MK	E
F. virescens v. *capitata* Krasske	-	+	-	+	-
Frustulia rhomboides v. *amphipleuroides* Grun.	-	+	-	-	+
Gomphonema acuminatun Ehr.	+	+	-	-	-
G. acuminatum v. *coronata* (Ehr.) W.Sm.	-	-	+	-	-
G. abbreviatum (Agardh.) Kütz.	+	-	+	-	+
G. angustatum v. *producta* Grun.	-	-	-	-	+
G. bohemicum Reichelt & Fricke	+	+	+	+	+
G. constrictum Ehr.	+	-	-	-	-
G. gracile Ehr.	-	+	-	-	-
G. lanceolatum Ehr.	+	+	+	+	+
G. longipes v. *subclavata* Grun.	-	+	+	-	+
G. olivacium (Lyngb.) Kütz.	+	+	+	+	+
G. parvulum Kütz.	+	+	+	+	+
G. parvulum v. *exilis* Grun.	+	+	+	+	+
G. ventricosum Greg.	+	-	-	-	-
Gyrosigma acuminatum Kütz.	+	+	+	-	+
Hantzschia amphioxys f. capitata O. Mull.	-	-	-	+	+
Melosira granulata (Ehr.) Ralfs.	-	-	-	-	+
M. islandica O. Mull.	+	+	+	+	+
M. varians C.A. Agardh.	+	+	+	+	-
Meridion circulare Agardh.	+	+	+	-	+
Navicula bacilliformis Grun.	-	-	-	-	+
N. cryptocephala Kütz.	+	+	+	+	+
N. cuspidata Kütz.	+	+	-	-	+
N. dicephala (Ehr.) W.Sm.	-	-	-	+	-
N. gracilis Ehr.	+	+	-	+	+
N. graciloides A. Mayer	+	+	+	-	+
N. hungarica v. *capitata* (Ehr.) Cl.	-	-	-	-	+
N. lapidosa Krasske	-	-	+	-	-
N. minima v. *atomoides* (Grun.) Cl.	-	-	-	-	+
N. placentula (Ehr.) Grun.	-	+	-	+	+

Table 18. Continued.

	M	SB	HS	MK	E
N. placentula v. rostrata A. Meyer	-	-	+	+	+
N. pupula Grun.	+	+	-	-	-
N. pupula v. rectangularis (Greg.) Grun.	-	-	+	-	-
N. radiosa Kütz.	+	+	+	+	+
N. rhychocephala Kütz.	+	+	-	+	-
N. scoliopleuroides Quint	-	-	-	-	+
Neidium affine (Ehr.) Cl.	-	-	-	+	-
N. affine v. amphirhynchus (Ehr.) Cl.	-	-	-	+	-
Nitzschia acicularis W.Sm.	+	-	-	-	-
N. acuta Hantzsch.	-	-	+	-	-
N. amphibia Grun.	+	+	-	-	-
N. clausii Hantzsch.	-	-	-	+	-
N. commutata Grun.	-	+	-	-	-
N. fonticola Grun.	+	+	-	-	+
N. gracilis Hantzsch.	+	+	+	+	+
N. hantzschiana Rabh.	-	+	-	-	-
N. heurfleriana Grun.	-	-	-	-	+
N. ignorata	-	-	-	-	+
N. palea (Kütz.) W.Sm.	-	+	+	+	+
N. paleacea Grun.	-	-	-	-	+
N. recta Hantzsch.	-	-	+	-	-
N. romana Grun.	-	-	-	-	+
N. sublinearis Hust.	+	-	-	+	-
Opephora martyi Heribaud	-	-	-	-	+
Pinnularia gibba Ehr.	+	-	+	+	-
P. mesolepta (Ehr.) W.Sm.	+	+	+	-	-
P. molaris Grun.	-	-	+	-	-
P. nodosa v. constricta Mayer	-	-	-	-	+
P. viridis v. sudetica (Hilse) Hust.	-	-	-	+	-
Rhoicosphenia curvata (Kütz.) Grun.	+	+	+	+	+
Rhopalodia gibba (Ehr.) O. Mull.	+	+	+	+	-
R. gibberula (Ehr.) O. Mull.	+	+	+	+	-

Table 18. Concluded.

	M	SB	HS	MK	E
R. parallela (Grun.) O. Mull.	-	+	+	+	-
Stauroneis anceps Ehr.	-	-	-	+	-
S. phoenicenteron Ehr.	-	-	-	-	+
S. legumen Ehr.	+	-	-	-	-
Stephanodiscus astraea (Ehr.) Grun.	-	-	±	±	±
S. hantzschii Grun.	±	±	±	±	-
Surirella angustata Kütz.	-	-	+	+	+
S. didyma Kütz.	-	-	-	-	+
S. delicatissima Lewis	-	-	-	+	-
Surirella linearis v. *helvetica* (Brun.) Meister	+	-	-	-	-
S. ovalis Breb.	-	-	-	+	-
S. robusta v. *splendida* (Ehr.) V.H.	-	-	-	+	+
S. tenera Greg.	-	-	-	-	+
Synedra cyclopum Brutschii	-	-	-	-	+
S. capitata Ehr.	+	-	-	-	-
S. pulchella Kütz.	+	+	-	-	-
S. rumpens Kütz.	+	+	-	-	+
S. rumpens v. *familiaris* (Kutz.) Grun.	+	+	-	-	+
S. ulna (Nitzsch.) Ehr.	+	+	+	+	+
Tabellaria fenestrata (Lyngby.) Kütz.	+	+	+	+	+
T. flocculosa (Roth.) Kütz.	+	-	-	-	-

Figure 46.
Seasonal succession of the dominant epilithic algae in the Muskeg River.

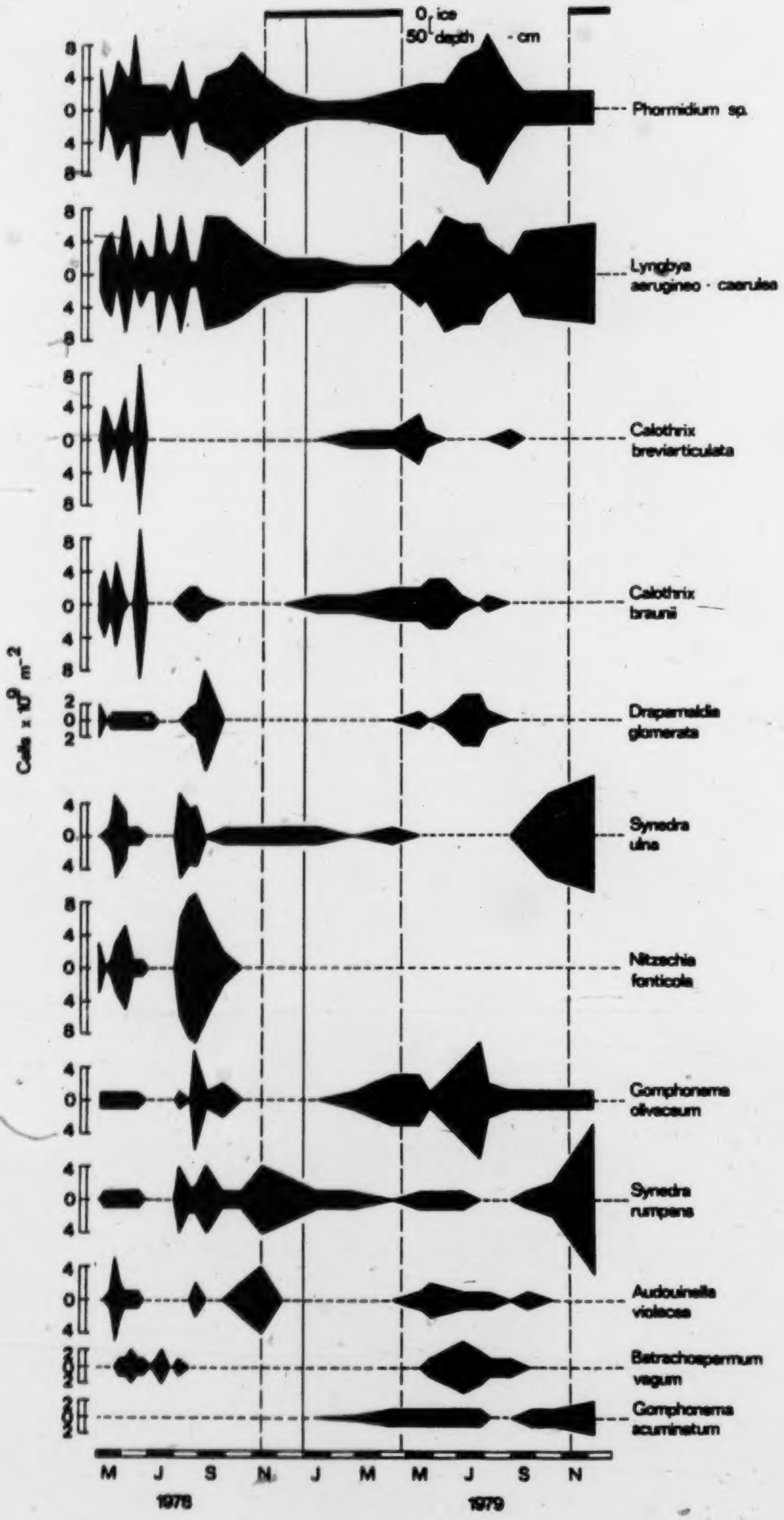
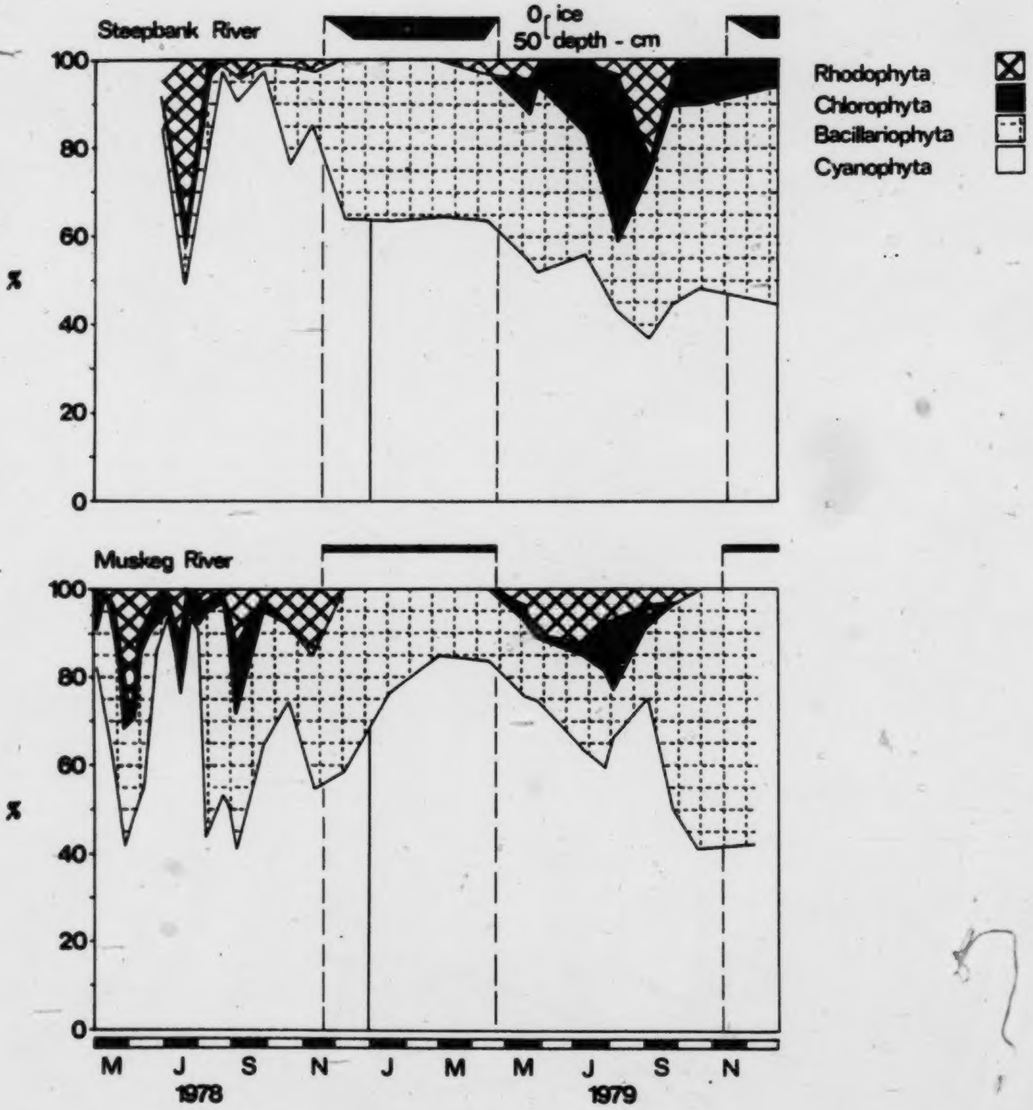

0 ice
50 depth - cm
Cells x 10^9 m^{-2}
8
4
0
4
8
2
Phormidium sp.
Lyngbya aerugineo - caerulea
Calothrix breviarticulata
Calothrix braunii
Draparnaldia glomerata
Synedra ulna
Nitzschia fonticola
Gomphonema olivaceum
Synedra rumpens
Audouinella violacea
Batrachospermum vagum
Gomphonema acuminatum
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 47.
Seasonal changes in the percentage composition of the epilithon in the Steepbank and Muskeg rivers.

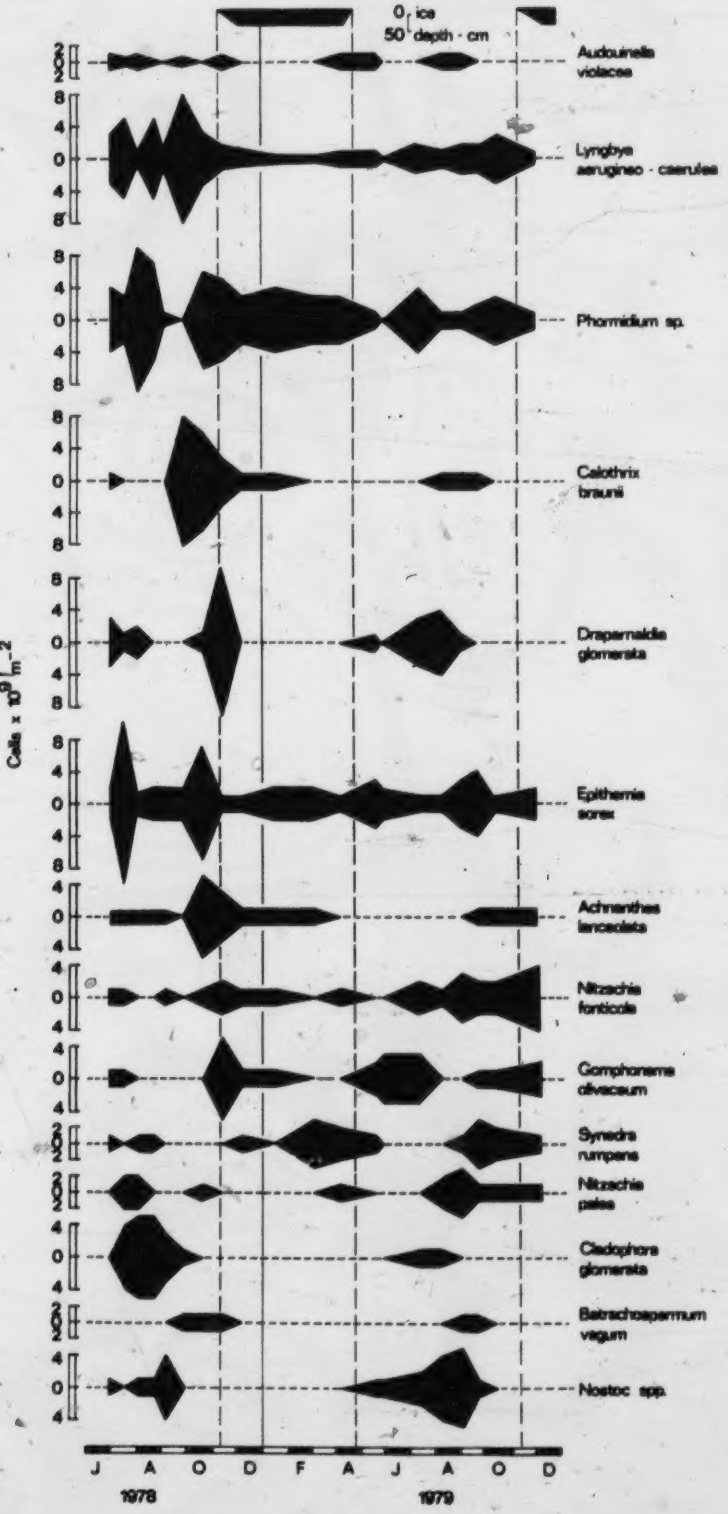

Steepbank River
0
50
ice
depth - cm
100
80
60
40
20
0
%
Rhodophyta
Chlorophyta
Bacillariophyta
Cyanophyta
Muskeg River
100
80
60
40
20
0
%
M
J
S
N
J
M
M
J
S
N
1978
1979

From December 1978 until April 1979 only Cyanophycean and Bacillariophycean algae were found. Two species of *Calothrix* began growth in early December and slowly increased in numbers during the winter to peak during May and early June 1979. Also, both *Lyngbya aerugineo-caerulea* and *Phormidium* sp. were present and these too began increasing in numbers, under ice cover, during March. The winter diatom community comprised mainly *Synedra ulna*, *Gomphonema oliaceum* (after January, 1979), *Synedra rumpens* and again after January, as well as for the first time, *Gomphonema acuminatum* (Figure 46).

From May 1979 Cyanophycean algae decreased in importance from 75% to 59.7% by late July. After an increase during August and early September, corresponding to large *Phormidium* and *Lyngbya* populations, further decreases to 41% by mid-October occurred. Diatoms continued to constitute the second major algal group from May to late July 1979 and again from early September until early December when they accounted for 56% of the benthic population. *Gomphonema olivaceum*, particularly, was important from May to late July, while *Synedra ulna* and *Synedra rumpens* dominated from early September onwards. Rhodophycean algae were again present during 1979. *Audouinella violaceae* peaked in late May and *Batrachospermum vagum* in mid-July. From May to early July, Rhodophycean algae were less conspicuous accounting for 10 to 12% of the total populations. Chlorophycean algae were less conspicuous with *Draparnaldia glomerata* the most important species during August. (Figure 46 and 47).

Cyanophycean algae were also dominant in the Steepbank River (Figures 47 and 48). Their importance, however, declined from a contribution of 85% of the total population during November 1978 and

Figure 48.
Seasonal succession of the dominant epilithic algae in the Steepbank River.


0 ice
50 depth - cm
Cells x 10⁹ m⁻²
Audouinella violacea
Lyngbya aeruginea - caerulea
Phormidium sp.
Calothrix braunii
Draparnaldia glomerata
Epithemia sorex
Achnanthes lanceolata
Nitzschia fonticola
Gomphonema olivaceum
Synedra rumpens
Nitzschia palea
Cladophora glomerata
Batrachospermum vagum
Nostoc spp.
8 4 0 4 8
4 0 4
2 0 2
J A O D F A J A O D
1978
1979

this decline continued during 1979. Lyngbya aerugineo caerulea and Phormidium sp. were again the most important species (Figure 48). A large population of Calothrix braunii developed during the autumn and early winter of 1978, but during 1979 the populations of these three algae never reached the 1978 levels. Increasing from a minimum of 49.5% in mid-July of 1978 the Cyanophycean algae attained a peak contribution of 98% by mid-August. In contrast, levels never exceeded 64.7% during 1979 (March) and by early December they had fallen to 44.5%.

During 1978 in the Steepbank River, Audouinella violaceae and Batrachospermum vagum were important, also peaking in mid-July (39.3%). Both species were present during 1979, however, they contributed slightly less and they appeared later in the year (August - September). Diatoms were important and steadily increased as the Cyanophycean algae decreased. Epithemia sorex was most prevalent during July and late autumn/early winter 1978. Achnanthes lanceolata peaked along with Epithemia during this latter period. Then, as ice formed Nitzschia fonticola and Gomphonema olivaceum peaked. All these populations however, decreased before March when numbers of Synedra rumpens increased. Peak diatom contributions occurred during 1978 October through December, averaging 24.3% of the total epilithic population. Levels were much higher during 1979, reaching 49.8% by early December. Spring 1979 diatom populations were dominated by Epithemia sorex and Gomphonema olivaceum. Then, from a low of 15.3% in August, diatom contributions increased as Epithemia sorex, Nitzschia fonticola, Gomphonema olivaceum, Synedra rumpens and Nitzschia palea became dominant. Chlorophycean algae were also more prevalent during 1979, particularly from July to August when large populations of Draparnaldia glomerata and Cladophora glomerata developed (figures 47 and 48) contributing 28 to 38% of the benthic community.

Cyanophycean algae were the most important algal group in the MacKay River (Figure 49), particularly during 1978. However, during the following year diatoms assumed a far greater importance, accounting for 100% of the community on June 2 and December 9 (Figure 49). The epilithon of the MacKay River was also dominated by far fewer algal species than the other four rivers (Figure 50). Lyngbya aerugineo caerulea, Calothrix braunii and Anabaeana affinis were the dominant Cyanophycean algae during 1978 (Figure 50), Cladophora glomerata and Chlamydomonas spp., the dominant Chlorophycean algae; and Epithemia sorex the dominant diatom. During 1978, Lyngbya and Calothrix maxima coincided during mid-July when Cyanophycean algae accounted for 99.3% of the total epilithic algal community, whereas, during 1979 only the spring peaks coincided. The summer peak of Calothrix occurred during mid July while that of Lyngbya did not occur until early September. At each time, Cyanophycean algae accounted for 92.9% and 55.6% of the total community. Chlorophycean algae constituted 47.3% of the total community in early August 1978, corresponding to populations of Chlamydomonas spp. and Cladophora glomerata.

The only other major contribution occurred under ice-cover in April (47.4% Cladophora glomerata). From here, no one particular Chlorophycean alga dominated and as a group occurred only in small numbers. Diatoms accounted for a far greater proportion of the epilithon during 1979, particularly because of Epithemia sorex which had a restricted distribution during 1978. In contrast, during 1979 it was present on all but one sampling date in far greater numbers.

Figure 49.
Seasonal changes in percentage composition of the epilithon in the MacKay and Hangingstone rivers.

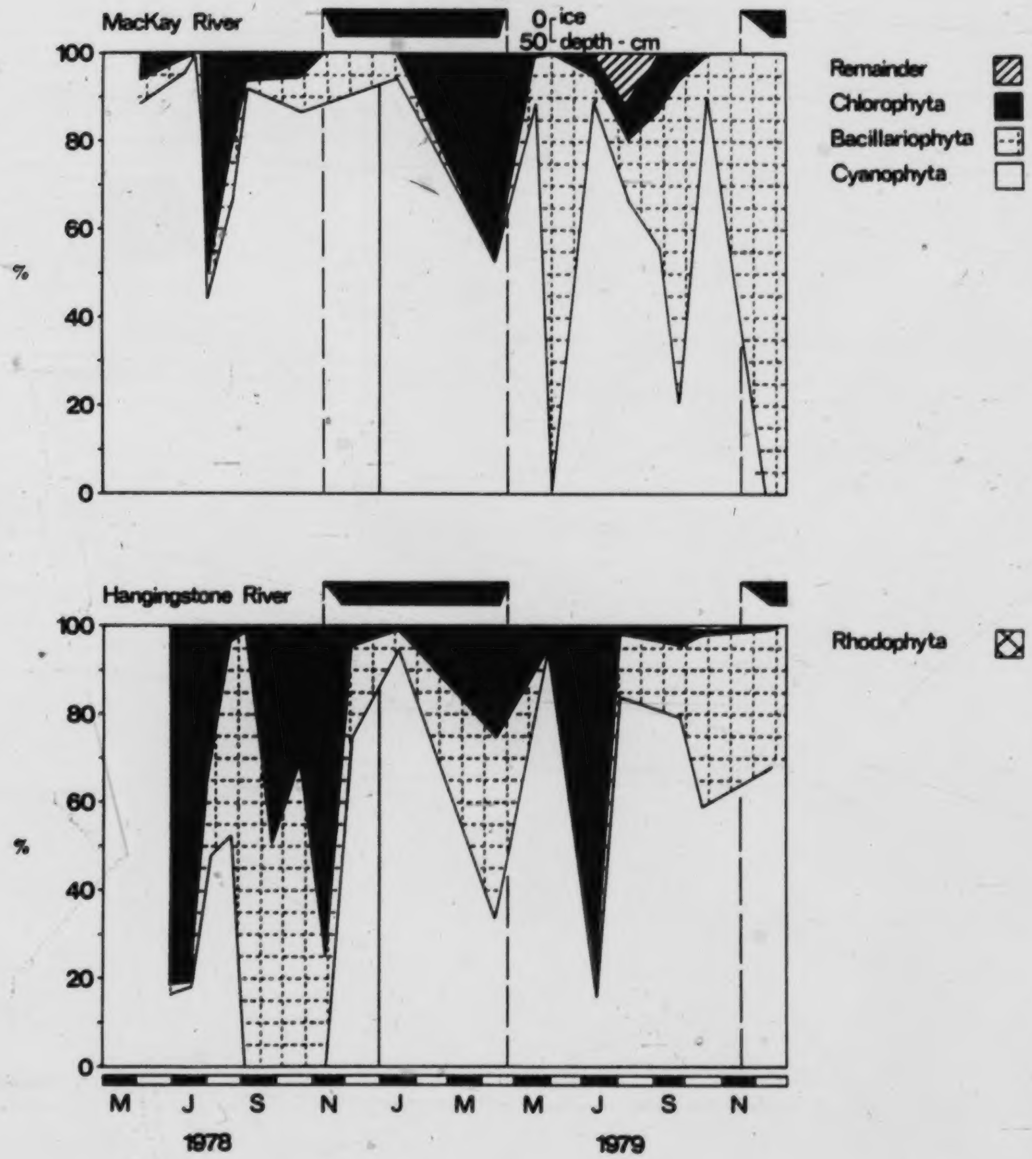
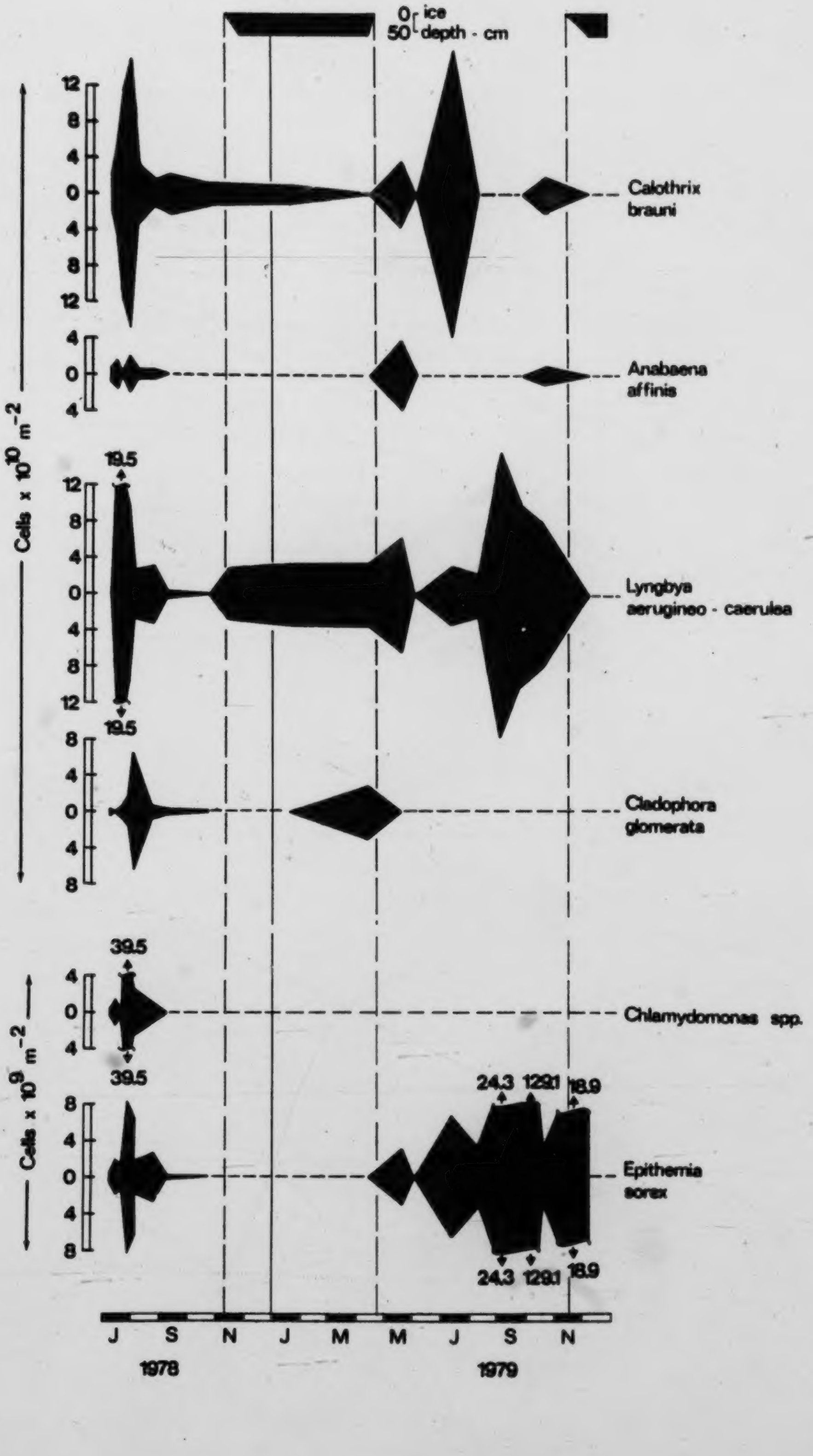

MacKay River
0 ice
50 depth - cm
100
80
60
40
20
0
%
Remainder
Chlorophyta
Bacillariophyta
Cyanophyta
Hangingstone River
Rhodophyta
M
J
S
N
J
M
M
J
S
N
1978
1979

Figure 50.
Seasonal succession of the dominant epilithic algae in the MacKay River.


0
50
ice
depth - cm
Cells x 10^{10} m^{-2}
12
8
4
0
4
8
12
Calothrix brauni
4
0
4
Anabaena affinis
19.5
12
8
4
0
4
8
12
19.5
Lyngbya aerugineo - caerulea
8
4
0
4
8
Cladophora glomerata
Cells x 10^{9} m^{-2}
39.5
4
0
4
39.5
Chlamydomonas spp.
24.3
129.1
18.9
8
4
0
4
8
24.3
129.1
18.9
Epithemia sorex
J
S
N
J
M
M
J
S
N
1978
1979

In the Hangingstone River Cyanophycean algae were not as abundant as in the other four rivers during 1978 (Figure 49). Initially, Chlorophycean algae accounted for 81% of the total population, with Stigeoclonium pachydermum being most important (Figure 51). However, after mid-July this alga occurred rarely. By early August, Cyanophycean algae had increased to 47.9%, reaching the 1978 maximum of 52.3% at the end of this month. Anabaena affinis, Calothrix braunii, and Lyngbya aerugineo-caerulea were the dominant Cyanophycean algae. From late August until November no Cyanophycean algae were found. Instead, by early September diatoms acounted for 98.8% of the total community (mainly Epithemia turgida). Diatom contribution thereafter decreased, reaching a low of 4.3% in mid-January. Concomitant with this decrease, Chlorophycean algae (mainly Cladophora glomerata) increased in importance, and also Cyanophycean algae (from November 1978) when Anabaena affinis and Calothrix Braunii reappeared. By mid-April diatoms were the most important (40.3% - mainly Gomphonema olivaceum) followed by Cyanophycean and Chlorophycean algae; 33.2% and 26.5% respectively. However, by the end of May the Cyanophycean algae accounted for 93.9% of the total community when Lyngbya aerugineo-caerulea dominated. Chlorophycean algae dominated during July (77.3% - mainly Chlorella vulgaris). Thereafter they were quite insignificant with Cyanophycean algae (mainly Calothrix) and diatoms (mainly Epithemia turgida) dominating.

Cyanophycean algae in the Ells River dominated on all but two occasions (Figure 52 and 53). The dominant species were Lyngbya aerugineo-caerulea, Calothrix braunii and Anabaena affinis. Lyngbya was always present producing its largest populations during autumn 1978 and

Figure 51.
Seasonal succession of the dominant epilithic algae in the Hangingstone River.

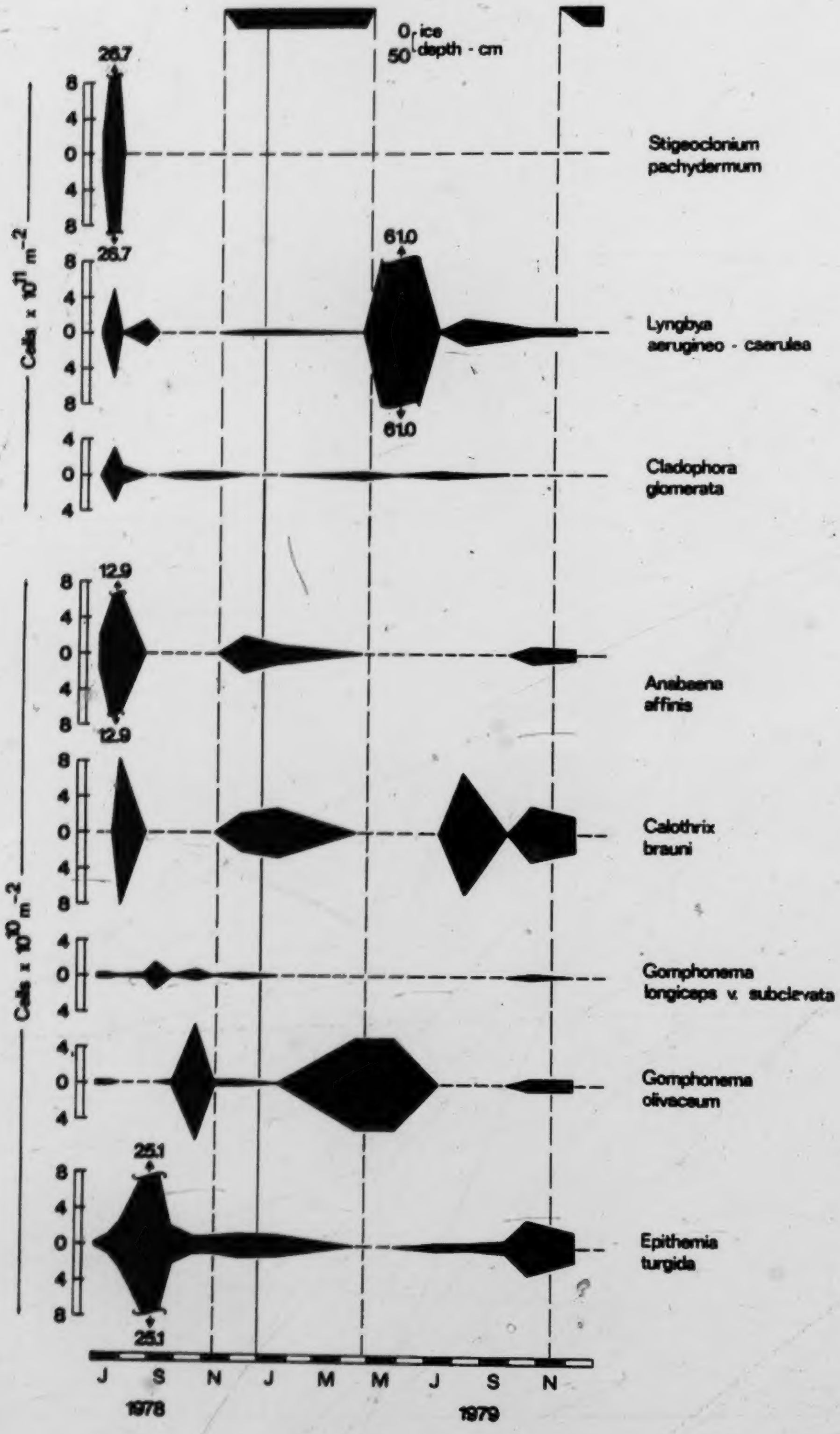

0
ice
50
depth - cm
26.7
26.7
61.0
61.0
12.9
12.9
25.1
25.1
8
4
0
Cells x 10^11 m^-2
Cells x 10^10 m^-2
Stigeoclonium pachydermum
Lyngbya aerugineo - caerulea
Cladophora glomerata
Anabaena affinis
Calothrix brauni
Gomphonema longiceps v. subclevata
Gomphonema olivaceum
Epithemia turgida
J
S
N
J
M
M
J
S
N
1978
1979
?

Figure 52.
Seasonal changes in the percentage composition
of the epilithon in the Ells River.

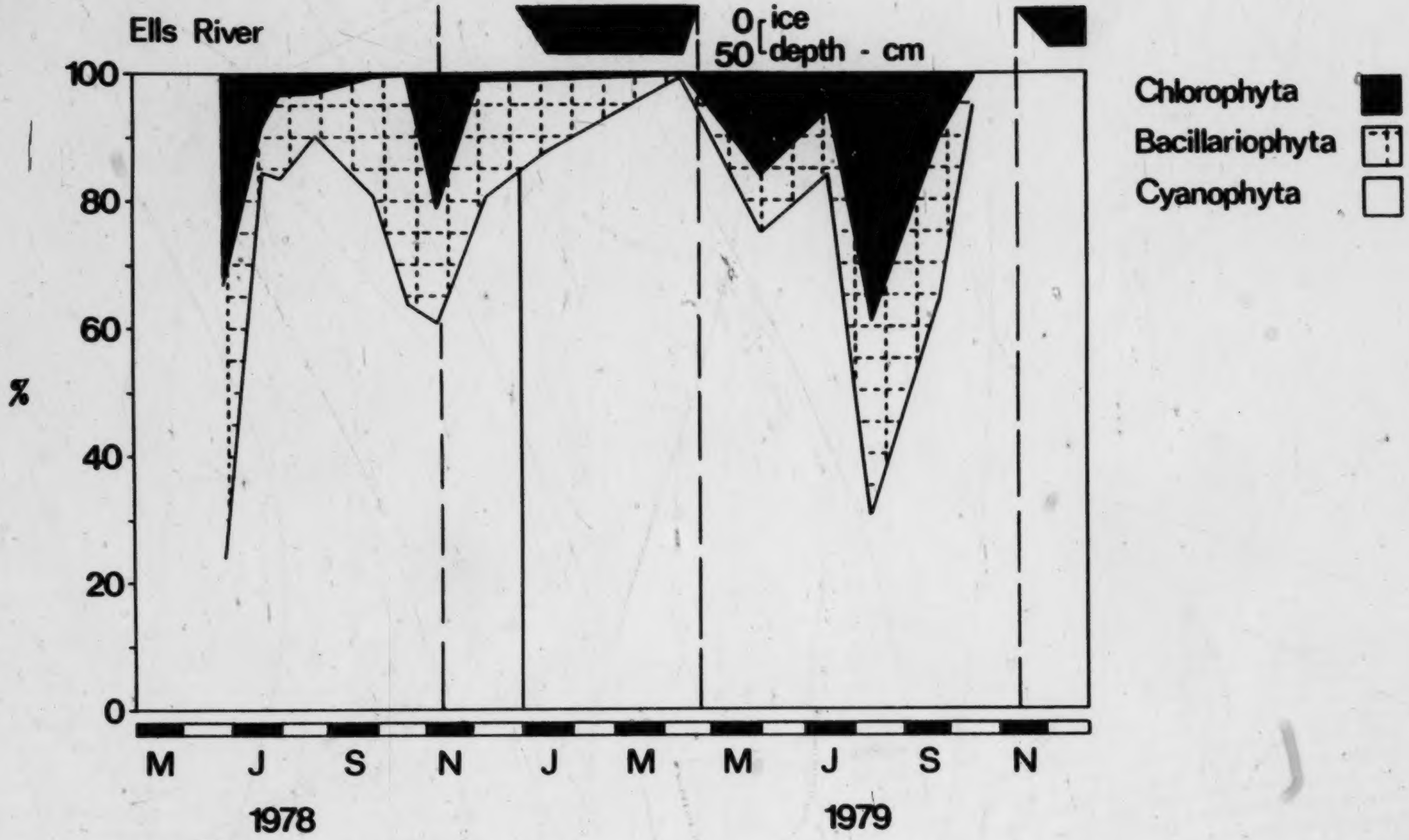
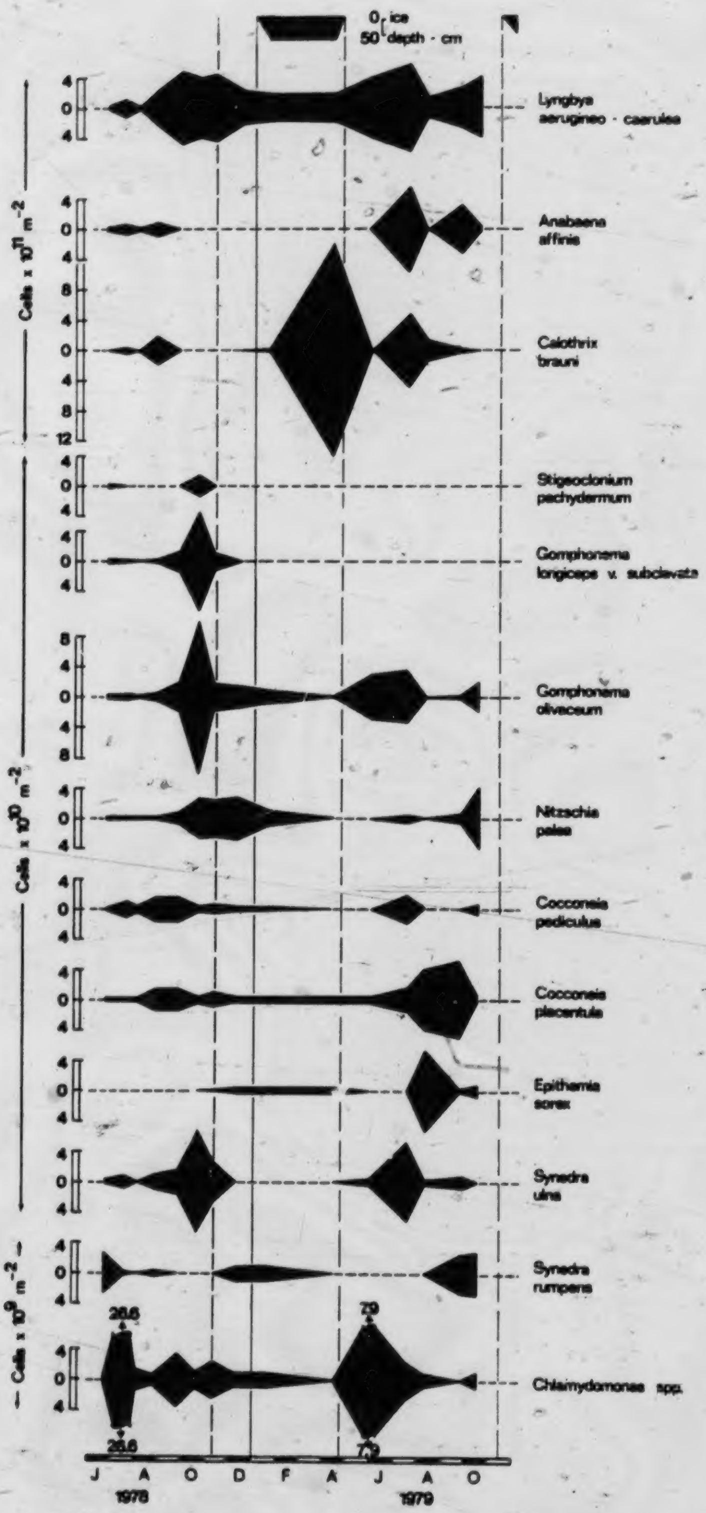

Ells River
0 ice
50 depth - cm
100
80
60
40
20
0
%
M
J
S
N
J
M
M
J
S
N
1978
1979
Chlorophyta ■
Bacillariophyta ▨
Cyanophyta ☐

Figure 53.
Seasonal succession of the dominant epilithic
algae in the Ells River.


0 ice
50 depth - cm
Cells x 10^11 m^-2
Cells x 10^10 m^-2
Cells x 10^9 m^-2
4
0
4
8
12
Lyngbya aerugineo - caerulea
Anabaena affinis
Calothrix brauni
Stigeoclonium pachydermum
Gomphonema longiceps v. subclavata
Gomphonema olivaceum
Nitzschia palea
Cocconeis pediculus
Cocconeis placentula
Epithemia sorex
Synedra ulna
Synedra rumpens
Chlamydomonas spp.
26.6
7.9
J
A
O
D
F
A
J
A
O
1978
1979

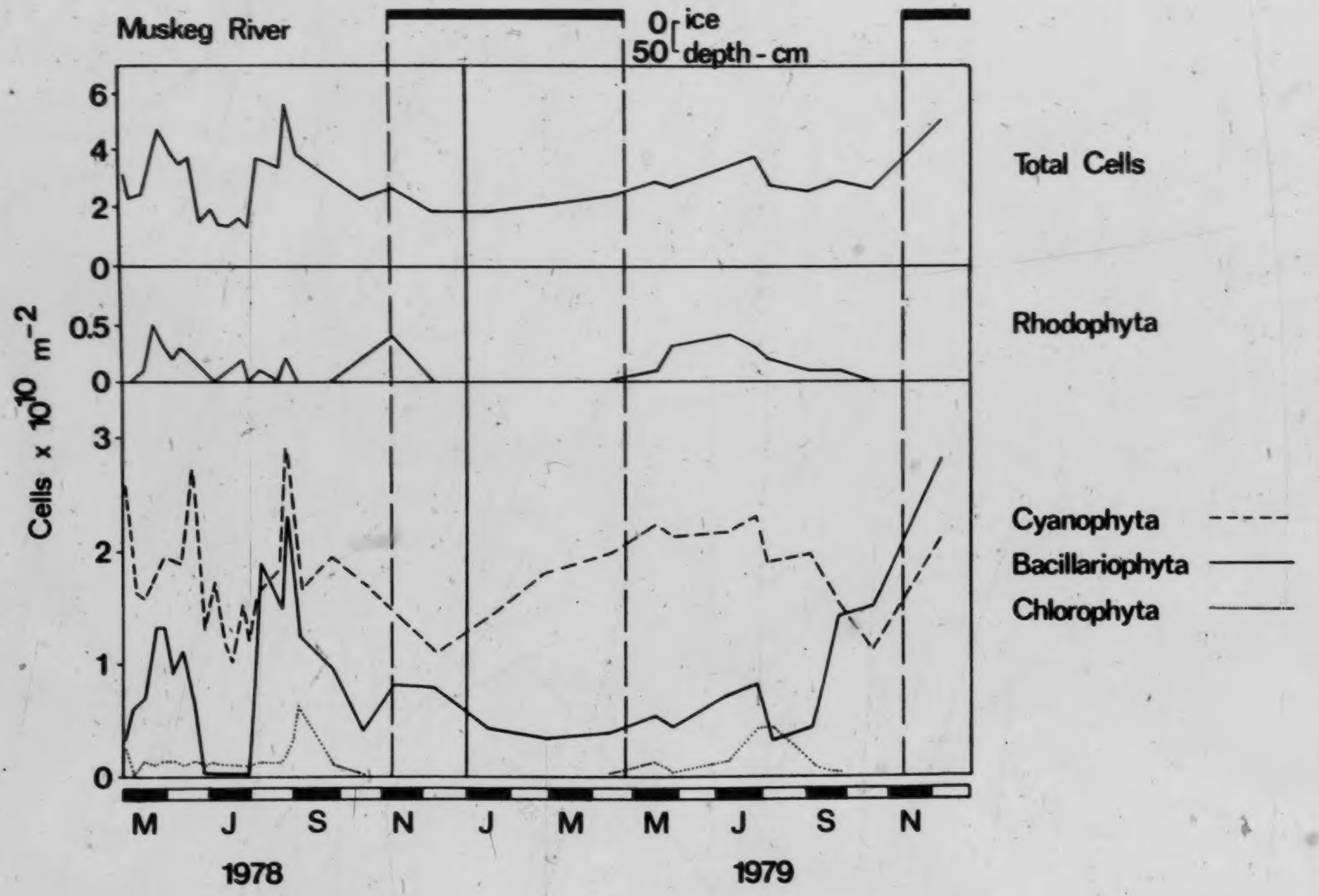
July 1979; Calothrix braunii peaked in April and July 1979, although like Anabaena affinis, smaller populations were present during 1978 with a small peak occurring in September; and Anabaena peaked in July and late September 1979.

On those two occasions that Cyanophycean algae did not dominate, late June 1978 and early August 1979 respectively, diatoms and chlorophycean algae were numerically more important. In late June 1978, Synedra ulna, Synedra rumpens, Cocconeis pediculus, Gomphonema olivaceum and Gomphonema longiceps var. subclavata were all present (Figure 53); in August 1979, Epithemia sorex and Cocconeis placentula were the dominant diatoms. In both instances the dominant Chlorophycean algae were Chlamydomonas spp.

4.3.2.1.2 Cell Numbers

In the Muskeg River total cell numbers peaked in the spring and autumn of 1978, but in 1979 a summer peak in July occurred between a much smaller spring and a larger autumn peak (Figure 54). The dominant species during these peaks are shown in Table 19. The species composition was very similar in both years in the spring and autumn maxima. However, Nitzschia fonticola and Synedra ulna were not present in the 1979 spring peak, and Batrachospermum vagum and Gomphonema olivaceum present in spring 1979 were absent in 1978. Similarly, Draparnaldia glomerata and Gomphonema olivaceum were present during the summer maximum of 1979. Gomphonema acuminatum only contributed significantly in autumn 1979. Cyanophycean algae were almost always the dominant algae numerically (Figure 54). Exceptions occurred during the autumn each year. Diatoms comprised the next most numerous division followed by Chlorophycean and Rhodophycean algae. The range of total

Figure 54.
Seasonal changes in total cells, Cyanophyta, Bacillariophyta, Chlorophyta and Rhondophyta in the Muskeg River.


Muskeg River
0 ice
50 depth - cm
Cells x 10^10 m^-2
6
4
2
0
0.5
0
3
2
1
0
Total Cells
Rhodophyta
Cyanophyta
Bacillariophyta
Chlorophyta
M
J
S
N
J
M
M
J
S
N
1978
1979

cells, diatoms, Chlorophycean, Cyanophycean and Rhodophycean algae for the Muskeg river is presented in the following Table 20.

Table 19: The algae dominant during the spring, summer, and autumn cell number peaks in the Muskeg River.

Year		Maximum	
	Spring	Summer	Autumn
1978.	*Phormidium* sp.	no maximum	*Phormidium* sp.
	Lyngbya aerugineo-caerulea		*Lyngbya aerugineo-caerulea*
	Calothrix breviarticulata		*Calothrix braunii*
	Calothrix braunii		*Draparnaldia glomerata*
	Synedra ulna		*Synedra ulna*
	Nitzschia fonticola		*Nitzschia fonticola*
	Audouinella violacea		*Gomphonema olivacium*
1979.	*Phormidium* sp.	*Phormidium* sp.	*Lyngbya aerugineo-caerulea*
	Lyngbya aerugineo-caerulea	*Lyngbya aerugineo-caerulea*	*Synedra ulna*
	Calothrix breviarticulata	*Draparnaldia glomerata*	*Synedra rumpens*
	Calothrix braunii	*Gomphonema olivacium*	*Gomphonema acuminatum*
	Gomphonema olivaceum	*Batrachospermum vagum*	*Phormidium* sp.
	Audouinella violacea		
	Batrachospermum vagum		

Table 20

Mean and Range of total cells numbers, Diatoms, Cyanophycean, Chlorophycean and Rhodophycean algae in the Muskeg River for the study period

	Range cells 10^{10} m^{-2}	Mean (arithmetic) cells $10^{10}m^{-2}$
Total Cells	1.30 - 5.63	2.90
Cyanophyta	1.02 - 2.90	1.78
Bacillariophyta	0.01 - 2.30	0.79
Chlorophyta	0 - 0.61	0.12
Rhodophyta	0 - 0.50	0.13

During 1978 in the Steepbank River, two algal maxima occurred, one during late July and a second, the largest, during October (Figure 55). Thereafter the populations remained high, decreasing only slightly during March of 1979. The winter population was dominated by Phormidium sp., Epithemia sorex, and Synedra rumpens (table 21). A small spring peak was apparent in 1979 followed by larger summer and winter peaks. Again, species composition was very similar at the maxima each year, although in spring 1979 Phormidium sp. was not as prevalent as in 1978 and the two diatoms Gomphonema olivaceum and Synedra rumpens were important only in 1979. Also, four species not found in 1978, Draparnaldia glomerata, Nitzschia palea, Nostoc spp. and Gomphonema olivaceum were dominant during summer 1979. Draparnaldia glomerata also occurred during the autumn peak in 1978. Only this species and Calothrix braunii were absent from the 1979 autumn peak.

Figure 55.
Seasonal changes in total cells, Cyanophyta, Bacillariophyta, Chlorophyta and Rhondophyta in the Steepbank River.

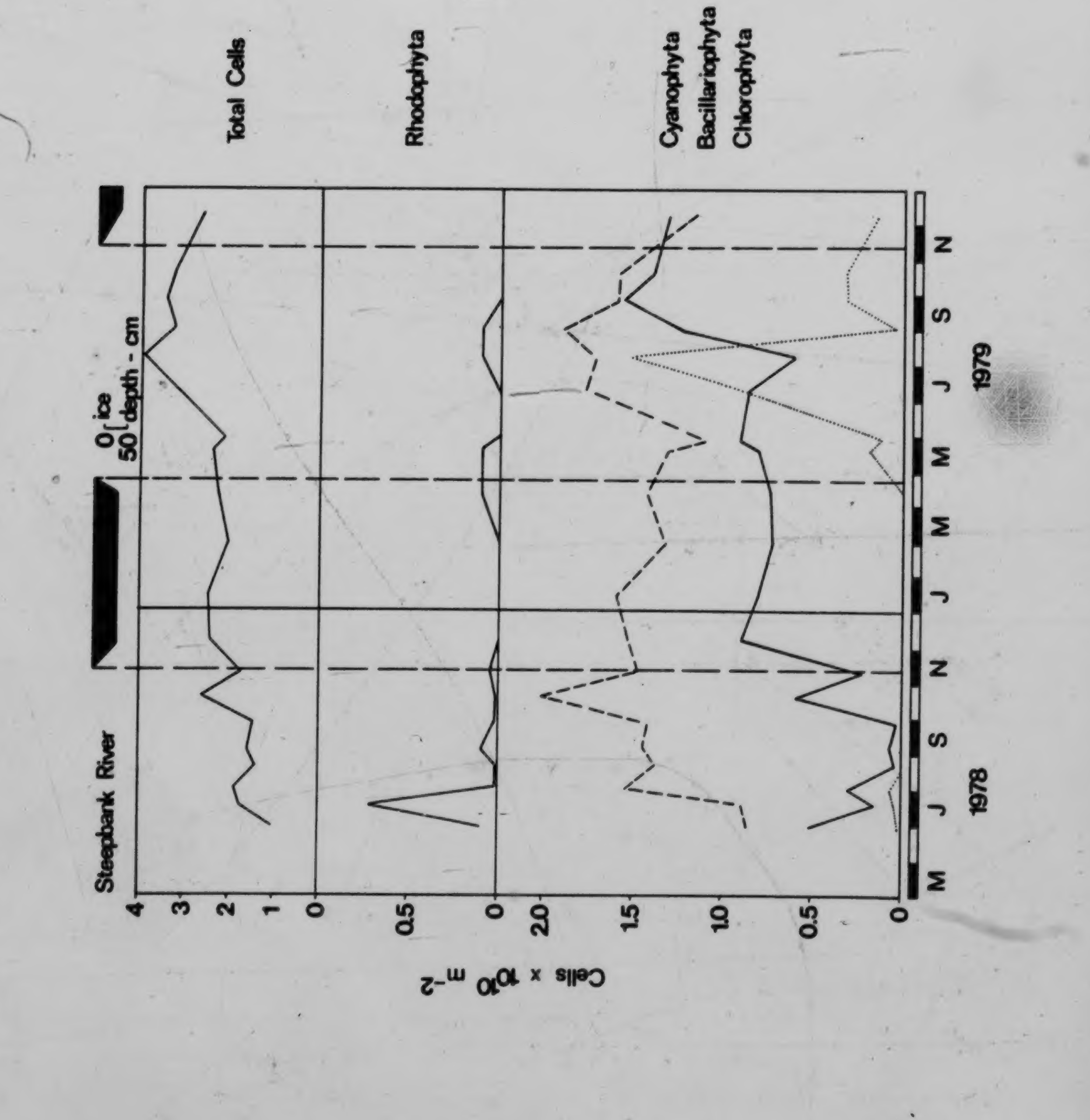

Steepbank River
0 ice
50 depth - cm
Total Cells
Rhodophyta
Cyanophyta
Bacillariophyta
Chlorophyta
Cells x 10^{10} m^{-2}
4
3
2
1
0
0.5
0
2.0
1.5
1.0
0.5
0
M
J
S
N
J
M
M
J
S
N
1978
1979

Table 21: The algae dominant during the spring, summer, and autumn cell number peaks in the Steepbank River.

Year	Maximum		
	Spring	Summer	Autumn
1978.	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*
	Epithemia sorex	*Phormidium* sp.	*Phormidium* sp.
	Phormidium sp.	*Cladophora glomerata*	*Calothrix braunii*
		Epithemia sorex	*Draparnaldia glomerata*
		Draparnaldia glomerata	*Epithemia sorex*
			Achnanthes lanceolata
			Gomphonema olivaceum
			Nitzschia fonticola
1979.	*Epithemia sorex*	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*
	Lyngbya aerugineo-caerulea	*Draparnaldia glomerata*	*Phormidium* sp.
	Gomphonema olivaceum	*Epithemia sorex*	*Epithemia sorex*
	Synedra rumpens	*Nitzschia palea*	*Nitzschia fonticola*
		Nostoc spp.	*Synedra rumpens*
		Gomphonema olivaceum	*Achnanthes lanceolata*
		Cladophora glomerata	*Gomphonema olivacium*

Cyanophycean algae were always most numerous except in early December 1979 (Figure 55, Table 21, 22), followed by diatoms. Only during mid-summer 1979 did a very large Chlorophycean community develop. The largest Rhodophycean population occurred in July 1978 when Audouinella violaceae was present.

Table 22

Mean and Range of total cell numbers, (Diatoms, Cyanophycean, Chlorophycean, and Rhodophycean algae) in the Steepbank River for the study period

	Range Cells 10^{10} m^{-2}	Mean Cells 10^{10} m^{-2}
Total Cells	1.02 - 3.93	2.36
Cyanophyta	0.86 - 2.00	1.45
Bacillariophyta	0.03 - 1.55	0.66
Chlorophyta	0 - 1.51	0.18
Rhodophyta	0 - 0.70	0.07

Sampling on the Mackay river did not commence until early July of 1978. Thereafter a large summer maximum of epilithic algae occurred (Figure 56). Cyanophycean algae were invariably the most numerous being followed by diatoms and Chlorophycean algae (Table 24). No autumn maxima occurred during 1978, but in 1979 spring, summer and autumn peaks appeared, each slightly larger than the previous season. However, the 1979 population numbers never approached the size of the 1978 epilithic numbers. Little change occurred in the dominant of these peaks (table 23) and diatoms along with Cyanophycean algae became very important during autumn 1979 with massive populations of Epithema sorex developing.

Figure 56.
Seasonal changes in total cells, Cyanophyta, Bacillariophyta and Chlorophyta in the MacKay River.

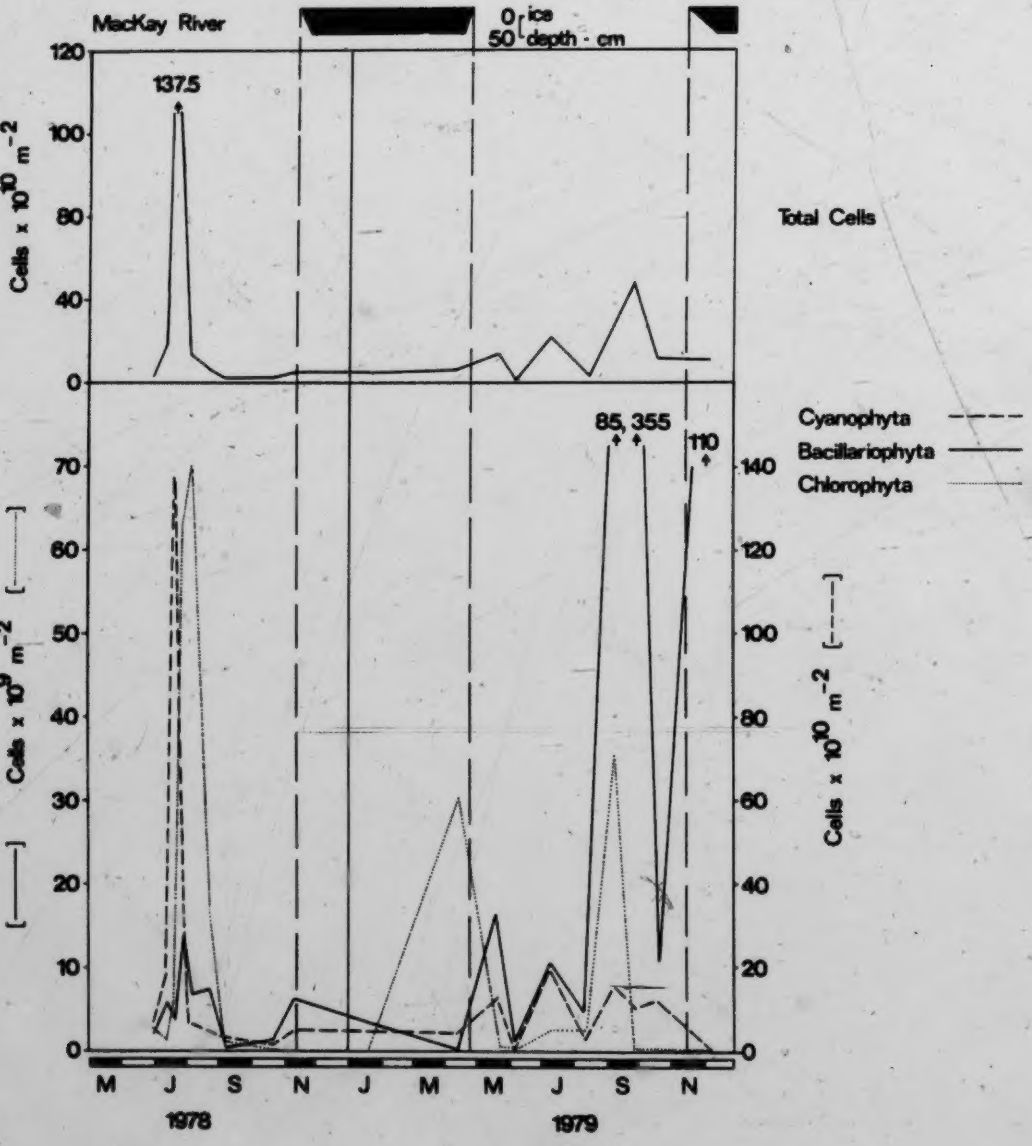

MacKay River
0
50
ice
depth - cm
120
100
80
40
0
Cells x 10^10 m^-2
137.5
Total Cells
Cyanophyta
Bacillariophyta
Chlorophyta
85, 355
110
70
60
50
40
30
20
10
0
Cells x 10^9 m^-2
140
120
100
80
60
40
20
0
Cells x 10^10 m^-2
M
J
S
N
J
M
M
J
S
N
1978
1979

Table 23. The algae dominant during the spring, summer, and autumn cell number peaks in the MacKay River.

Year		Maximum	
	Spring	Summer	Autumn
1978.	Not sampled	*Calothrix braunii*	No maximum
		Lyngbya aerugineo-caerulea	
		Cladophora glomerata	
		Chlamydomonas spp.	
		Epithemia sorex	
1979.	*Calothrix braunii*	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*
	Anabaena affinis	*Calothrix braunii*	*Epithemia sorex*
	Lyngbya aerugineo-caerulea	*Epithemia sorex*	
	Epithemia sorex		

TABLE 24

Mean and Range of total cell numbers (Diatoms Cyanophycean and Chlorophycean algae) in the Mackay River

	Range Cells 10^{10} m^{-2}	Mean Cells 10^{10} m^{-2}
Total Cells	0.10 - 137.50	20.30
Cyanophyta	0 - 136.50	15.40
Bacillariophyta	0 - 35.50	3.39
Chlorophyta	0 - 7.05	1.38

Sampling on the Hangingstone River also commenced during early July of 1978. During that year a large summer epilithic community developed, followed by a much smaller autumn one. The spring and summer peaks of 1979 merged and only a slight fall peak was evident (Figure 57).

Table 25: The algae dominant during the spring, summer, and autumn cell number peaks in the Hangingstone River.

Year		Maximum	
	Spring	Summer	Autumn
1978.	not sampled	*Stigeoclonium pachydermum*	*Epithemia turgida*
		Lyngbya aerugineo-caerulea	*Gomphonema olivacium*
		Cladophora glomerata	
		Anabaena affinis	
		Calothrix braunii	
1979.	Spring and Summer		
	Lyngbya aerugineo-caerulea		*Calothrix braunii*
	Calothrix braunii		*Epithemia turgida*
	Gomphonema olivaceum		

Stigeoclonium pachydermum was found only during July 1978. Gomphonema olivaceum was dominant during autumn 1978 as well as during the spring/ summer maximum of 1979. These algae formed only a small population during autumn 1979 (Table 25, Figure 57). Cyanophycean algae were again numerically dominant but, unlike the other four rivers, the second most numerous division was Chlorophycean algae followed by diatoms (Table 26).

TABLE 26

Mean and Range of total cell numbers (Diatoms, Cyanophycean, Chlorophycean algae) in the Hangingstone River

	Range cells 10^{10} m^{-2}	Mean cells 10^{10} m^{-2}
Total Cells	29.00 - 653.16	75.80
Cyanophyta	0 - 613.57	40.70
Bacillariophyta	0.30 - 31.50	5.64
Chlorophyta	0 - 299.70	23.80

Unlike the MacKay and Hangingstone Rivers, the Ells river did not have a very large summer peak of epilithic algae during 1978. Instead, 1979 was the year of maximum epilithic abundance. Autumn maxima were, however, comparable for both 1978 and 1979 (Figure 58). Cyanophycean algae were dominant, with Lyngbya aerugineo-caerulea dominant all the time (Table 27). In this river more diatom species contributed significantly than in the other four rivers (Table 27).

Figure 57.
Seasonal changes in total cells, Cyanophyta, Bacillariophyta and Chlorophyta in the Hangingstone River.

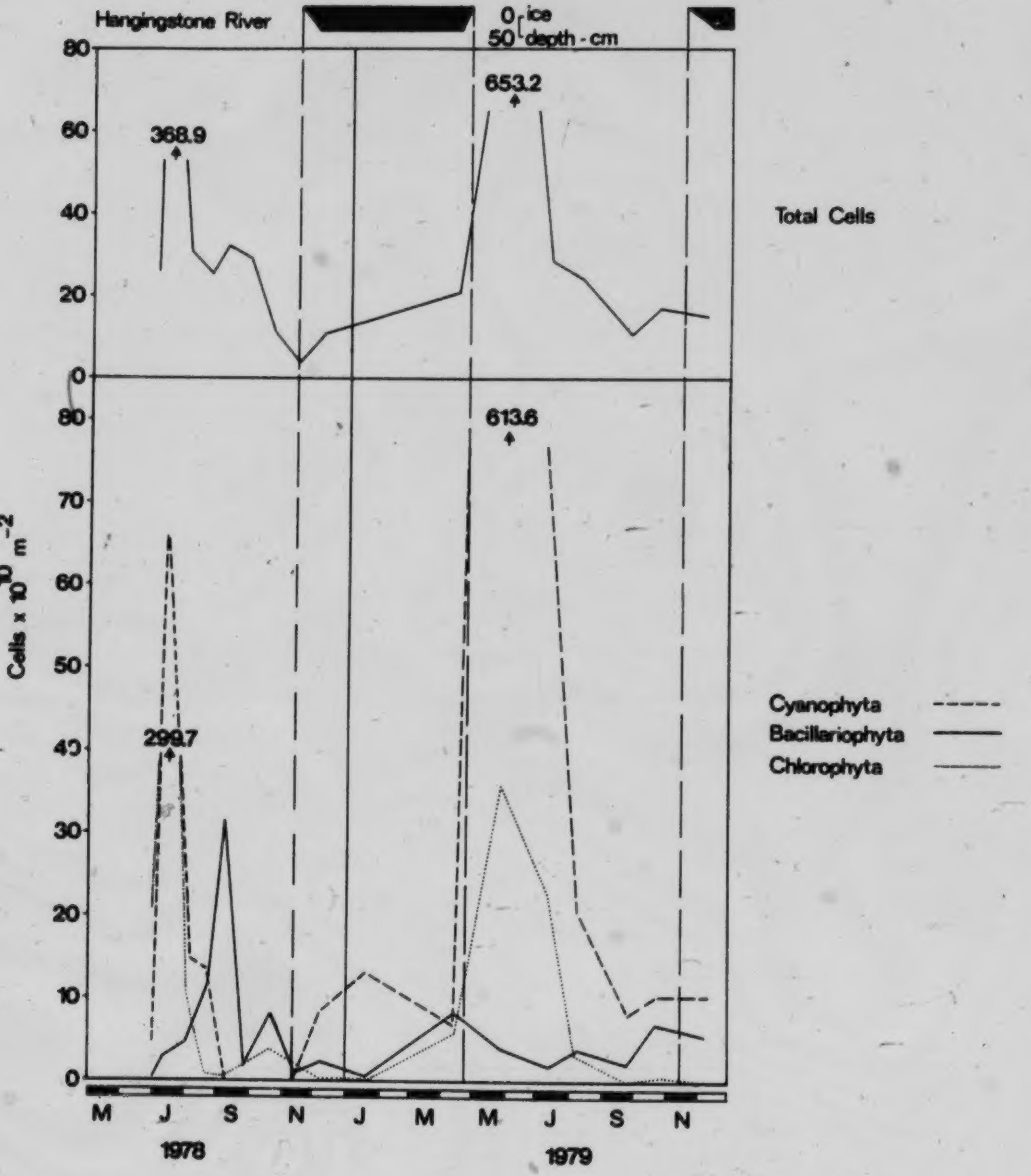

Hangingstone River
0 ice
50 depth - cm
80
60
40
20
0
368.9
653.2
Total Cells
Cells x 10^{10} m^{-2}
80
70
60
50
40
30
20
10
0
613.6
299.7
Cyanophyta
Bacillariophyta
Chlorophyta
M
J
S
N
J
M
M
J
S
N
1978
1979

Table 27: The algae dominant during the spring, summer, and autumn cell number peaks in the Ells River

Year		Maximum	
	Spring	Summer	Autumn
1978.	not sampled	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*
		Anabaena affinis	*Stigeoclonium pachydermum*
		Cocconeis pediculus	*Gomphonema longiceps* v. *subclavata*
		Synedra rumpens	*Gomphonema olivaceum*
		Chlamydomonas spp.	*Cocconeis pediculus*
			Cocconeis placentula
			Synedra ulna
			Chlamydomonas spp.
1979.	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*	*Lyngbya aerugineo-caerulea*
	Calothrix braunii	*Anabaena affinis*	*Gomphonema olivaceum*
	Gomphonema olivaceum	*Calothrix braunii*	*Nitzschia palea*
		Gomphonema olivaceum	*Cocconeis placentula*
		Synedra ulna	*Epithemia sorex*
			Synedra rumpens

Lyngbya was the dominant Cyanophycean algae in the summer of 1978, whereas it, along with *Anabaena affinis* and *Calothrix* sp., were codominant in 1979. Two diatoms, *Gomphonema olivaceum* and *Synedra ulna* were also present in 1979, whereas *Synedra rumpens* had been in 1978. The autumn peaks comprised many diatom species, some of which occurred both years (Table 27). However, only in 1978 was *Stigeoclonium pachydermum* found.

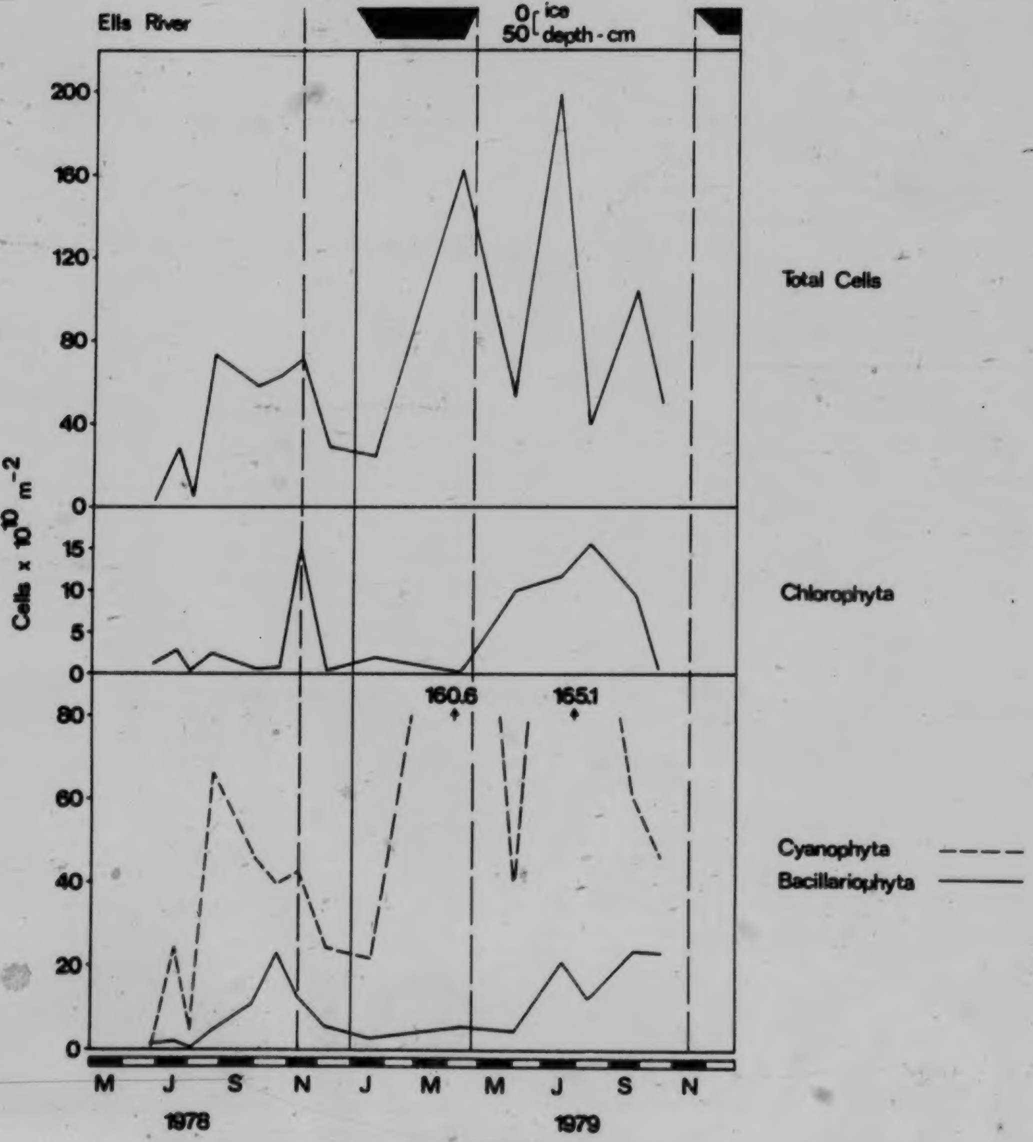
In summary, therefore Cyanophycean algae were generally dominant followed by diatoms and Chlorophycean algae in the Ells River (Table 28).

Table 28

Mean and Range of the Total Cell Numbers (Diatoms, Cyanophycean and Chlorophycean algae in the Ells River

	Range cells 10^{10} m^{-2}	Mean (arithmetic) cells 10^{10} m^{-2}
Total Cells	3.70 - 197.70	63.80
Cyanophyta	0.90 - 165.12	50.70
Bacillariophyta	0.51 - 23.98	8.50
Chlorophyta	0 - 15.49	4.60

Figure 58.
Seasonal changes in the total cell numbers of
Cyanophyta, Bacillariophyta and
Chlorophyta in the Ells River.


Ells River
0 ice
50 depth - cm
Cells x 10^10 m^-2
200
160
120
80
40
0
Total Cells
15
10
5
0
Chlorophyta
80
60
40
20
0
160.6
165.1
Cyanophyta
Bacillariophyta
M
J
S
N
J
M
M
J
S
N
1978
1979

4.3.3 Temporal Standing Crop Changes

4.3.1 Epilithon

Seasonal fluctuations of the epilithic standing crops in the Muskeg, Steepbank, Hangingstone, MacKay and Ells Rivers were compared using the singular rock brushing technique and transect methods in conjunction with primary productivity studies. The results are presented in figure 62. In the Muskeg River during 1978, chlorophyll a concentrations fluctuated more than during 1979, with spring, late summer and early winter peaks evident. The spring peak, like cell counts in 1979 was small, with the standing crop rising to a maximum in early December (Figure 59).

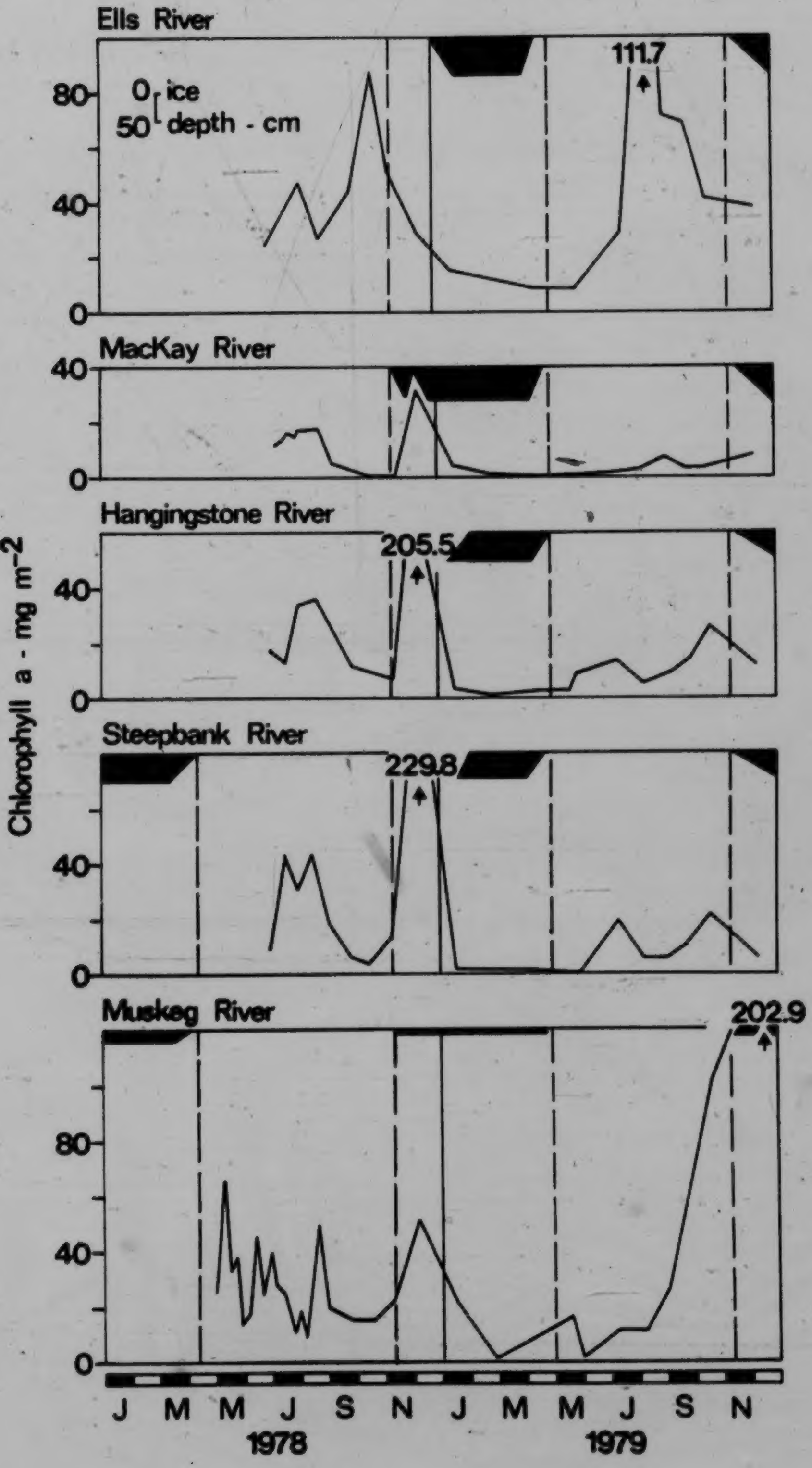
A summer/autumn chlorophyll peak was evident in the Steepbank River while a massive peak (229.8 mg chlorophyll a m^{-2}) occurred in early December 1978. During spring of 1979 a spring maximum was not detected; however, a small summer and a distinct autumn maxima occurred (Figure 59). Thus, a bimodal peak of epilithic standing crop was found to occur in the Steepbank River as well.

Standing crops in the Hangingstone River were very similar to those in the Steepbank River; the algal standing crop peaks occurred at the same time and achieved nearly the same size (205.5 mg chlorophyll a m^{-2}) and 229.8 mg chlorophyll a m^{-2}.

Chlorophyll a, like cell counts in the MacKay River, were lower than the other four rivers. Although this river supported a smaller epilithic biomass, a summer peak was evident as well as a late winter maximum following ice formation during 1978. Standing crops remained lower during 1979 with only a small peak during the autumn.

Epilithic standing crops fluctuated with similar seasonal patterns in the Ells River; however, during both 1978 and 1979 the autumn maximum

Figure 59.
Seasonal fluctuations in epilithic algal standing crop, as measured by chlorophyll a content in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
0 ice
50 depth - cm
111.7
80
40
0
MacKay River
40
0
Hangingstone River
205.5
40
0
Steepbank River
229.8
40
0
Muskeg River
202.9
80
40
0
Chlorophyll a - mg m-2
J M M J S N J M M J S N
1978
1979

preceeded that of the other four rivers. The development of late summer maxima was also followed by declining autumn standing crops despite the fact that species composition changes as noted earlier were similar to the other rivers.

A comparison of the standing crop means for the five rivers indicated that for the duration of the study, the Ells River supported the highest standing crop, followed by the Muskeg, Steepbank, Hangingstone and MacKay Table 29).

Table 29

Mean and Range of Standing Crop for Epilithon
As Measured by Chlorophyll _a_ content

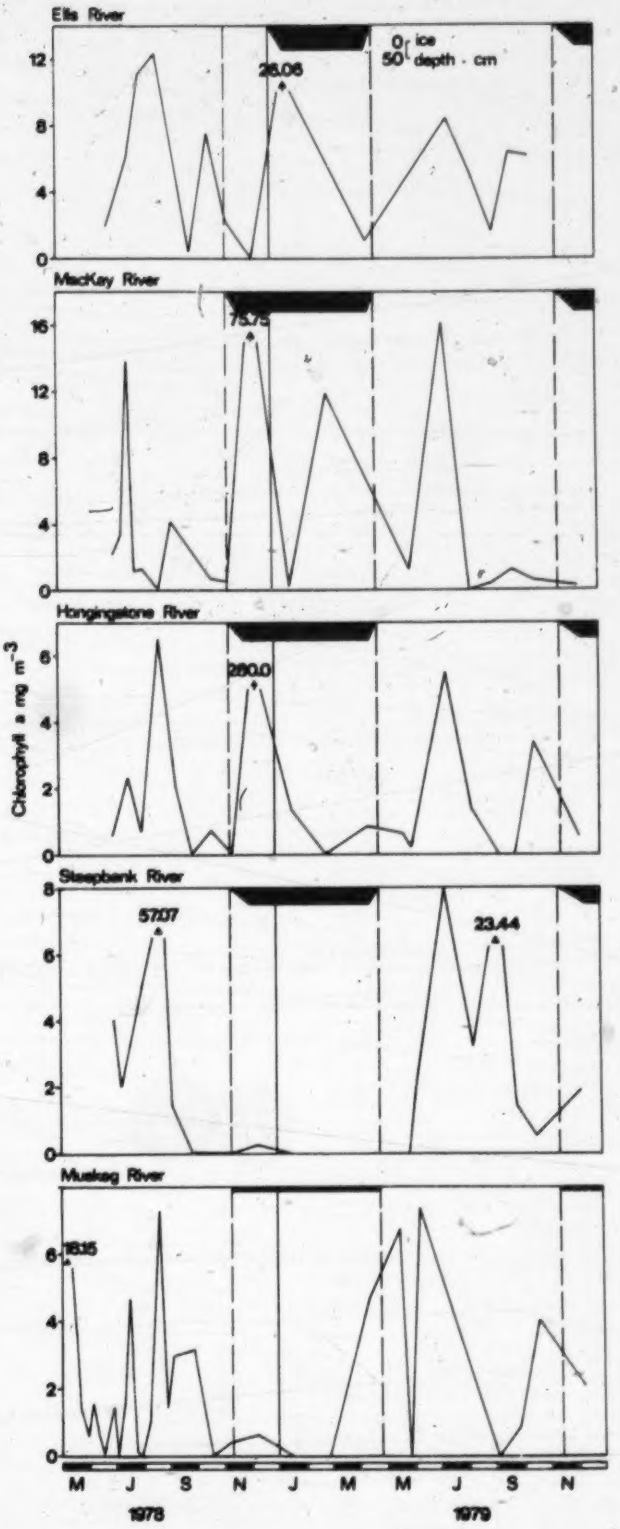
River	Range Chlorophyll _a_ mg m^{-2}	Mean Chlorophyll _a_ mg m^{-2}
Muskeg	1.33 - 202.95	30.46
Steepbank	0 - 229.84	22.99
MacKay	0.11 - 30.66	7.94
Hangingstone	1.42 - 205.46	22.35
Ells	8.38 - 111.72	43.23

4.3.3.1 Phytoplankton

Microscopic examination of planktonic lotic algae collected from the five rivers indicated that both senescing epilithic and lentic species were present. It was noted that desmids probably derived from muskeg runoff were also present. The standing planktonic crop fluctuations were very irregular (Figure 60).

Figure 60.

Standing crop, as measured by chlorophyll *a* content, of the planktonic algae in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ellis River
0
50
ice
depth - cm
26.06
MacKay River
75.75
Hangingstone River
280.0
Steepbank River
57.07
23.44
Muskeg River
16.15
Chlorophyll a mg m^{-3}
0
2
4
6
8
12
16
M
J
S
N
J
M
M
J
S
N
1978
1979

Despite the irregular nature of standing crop fluctuations, spring, summer and autumn peaks as well as some winter ones (eg. Ells, MacKay, Hangingstone) did occur. Peak planktonic standing crops frequently occurred during periods of peak epilithic standing crops and thereafter, suggesting that detached epilithic algae are the major component of the planktonic algae in these rather small brown water rivers. Planktonic standing crops were highest in the Hangingstone and lowest in the Muskeg River (Table 30).

Table 30

Range of Standing Crop for Plankton as Measured by Chlorophyll a content

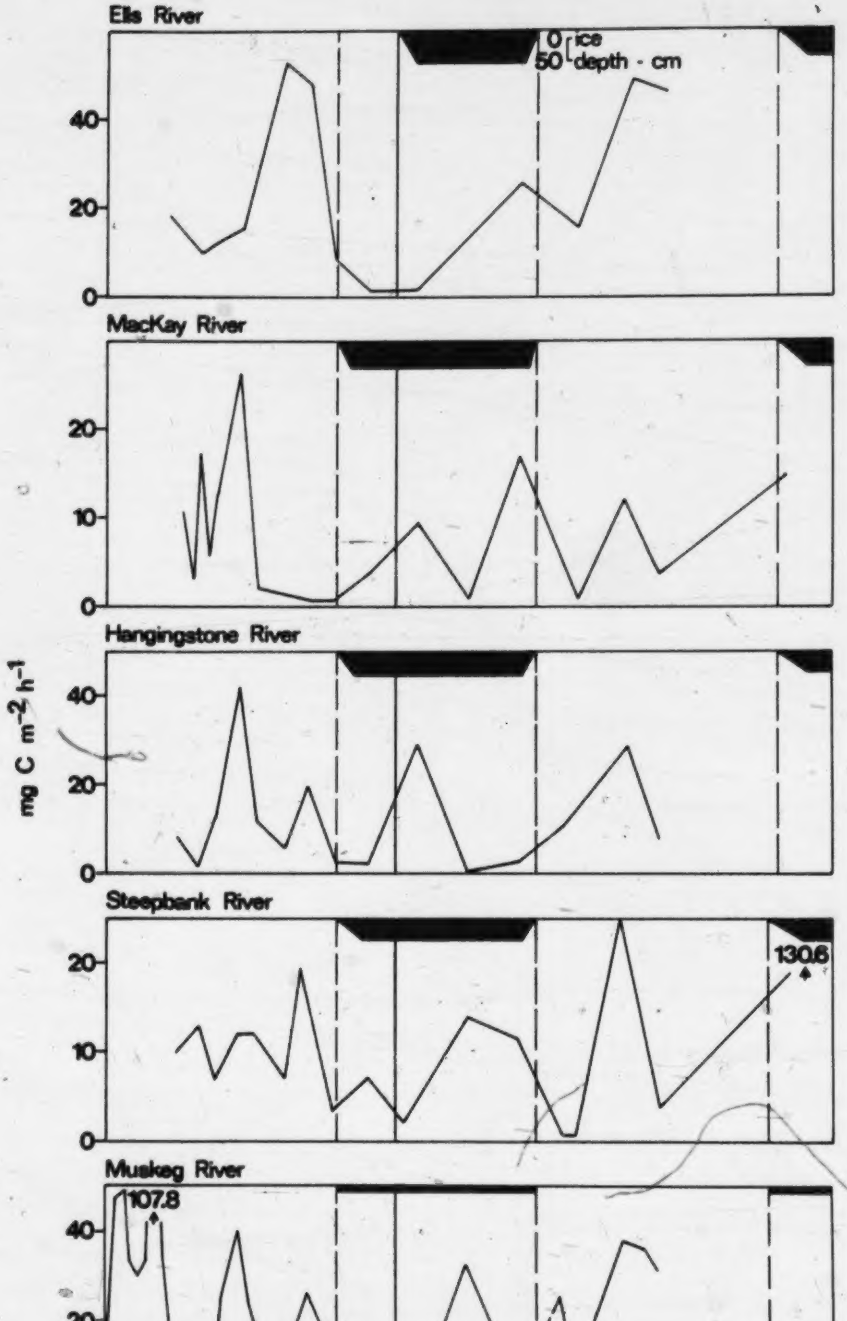
River	Range Chlorophyll a mg m^{-3}	Mean mg m^{-3}
Muskeg	0 - 18.15	2.93
Steepbank	0 - 57.07	5.42
MacKay	0 - 75.75	7.12
Hangingstone	0 - 280.00	15.11
Ells	0.01 - 26.06	6.44

4.3.4 Temporal Productivity Changes

4.3.4.1 Epilithon

Seasonal primary productivity fluctuations for each of the five rivers are illustrated in Figure 61. They were more variable than those for standing crops. Summer maxima occurred in all rivers, but spring and autumn maxima did not occur consistently except in the Muskeg River. Winter peaks occurred under ice and snow cover during January 1979 in the Hangingstone and MacKay rivers and during March in the Muskeg and

Figure 61.
Epilithic algal primary productivity in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


Ells River
0 ice
50 depth - cm
MacKay River
Hangingstone River
Steepbank River
130.6
Muskeg River
107.8
mg C m^-2 h^-1
0
10
20
40
M
J
S
N
J
M
M
J
S
N
1978
1979

Steepbank rivers, and late April in the Ells and MacKay Rivers. The range of productivity values for the five rivers is presented in table 31.

Table 31

Mean and range of epilithic ^{14}C uptake for each of the five rivers

River	Range mg C m^{-2} hr^{-1}	Mean mg C m^{-2} hr^{-1}
Muskeg	1.1 - 107.8	25.3
Steepbank	0.6 - 130.6	16.3
Hangingstone	0.1 - 41.9	12.4
MacKay	0.5 - 26.0	8.3
Ells	1.1 - 52.5	23.2

Mean productivity among the five rivers ranged from 8.3 mg C m^{-2} hr^{-1} (MacKay) to 25.3 mg C m^{-2} hr^{-1} (Muskeg). Although epilithic productivity was on average higher in the Muskeg River, the highest value was found in the Steepbank River.

Multiple linear regression of open water period primary production (epilithic) versus algal numbers, temperature, silica, pH, phosphorus, velocity, discharge, nitrogen, and total alkalinity revealed that diatom numbers were primarily related to productivity in the Muskeg River (r=.64) (Appendix 6 and 7). The remaining variables increased the multiple r value to 0.87. In the Steepbank River nitrate-nitrogen (r=.75) discharge and pH were primarily related to productivity. Phosphorus was the more important variable (of those examined) related to productivity in the Hangingstone River (r=.41), and the Ells River (r=.64). In the MacKay River Chlorophycean numbers (r=.51) were most highly correlated with epilithic productivity. Multiple linear regression analysis of these sample variables versus productivity (open water) for all the rivers combined indicated that Cyanophycean algal numbers are most highly correlated with productivity ($r=.28$). The remaining variable yielded a multiple r of 0.54 indicating that other factors influence primary productivity among these brown water alkaline streams. Mean epilithic chlorophyll a and productivity were positively correlated ($r=0.869$, $p< 0.10$), suggesting the presence of a possible biotic factor which influences epilithic primary productivity (Appendix 8).

4.3.4.2 Phytoplankton

Phytoplankton productivity was highly variable among the five rivers. Table 32 below presents the 1979 findings.

Table 32

Mean and range for phytoplankton ^{14}C uptake during 1979

Location	Range mg C m^{-3} hr^{-1}	Mean mg C m^{-3} hr^{-1}
Muskeg	7.4 - 90.5	46.5
Steepbank	0.8 - 61.2	26.8
Hangingstone	14.2 - 51.2	34.3
Ells	26.4 - 77.5	49.4
MacKay	0.2 - 68.9	34.4

The highest mean ^{14}C uptake rate of 49.4 mg C m^{-3} hr^{-1} was found to occur in the Ells River, which is located downstream of the Gardiner Lakes. Peak phytoplankton productivity occurred in the winter (January) under ice cover in Muskeg, during April (ice out) in the Steepbank and

Hangingstone and July in the MacKay and Ells. Phytoplankton productivity and standing crops were not related statistically.

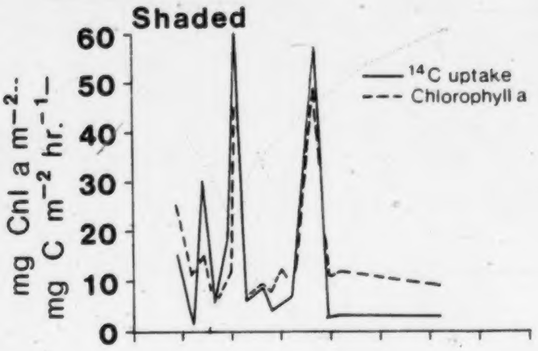
4.3.4.3 Microhabitat Differences

Since epilithic algal standing crops varied depending upon the microhabitat it followed that productivity would vary too. To confirm this, primary productivity was compared among the shore, midstream and midstream artificially shaded sites in the Muskeg River during 1978. The results are presented in figure 62.

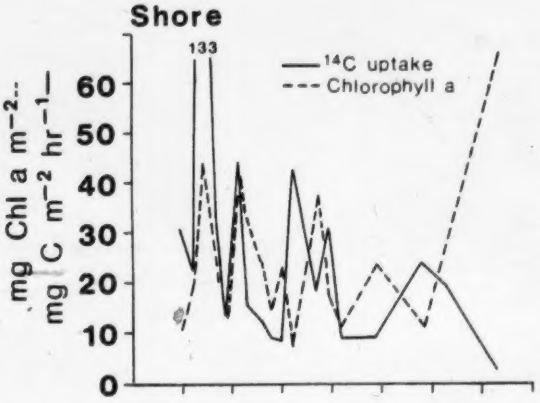
At the onset of this study on 29 May, productivity was higher at the shore site than midstream. It reached maximum at both sites in early June (133.0 and 83.0 mg C m^{-2} hr^{-1} respectively). Second peaks occurred at both sites in August but that at the shore site occurred earlier than the peak at the midstream site (Figure 62). Higher epilithic algal productivity continued at this midstream site until the late fall. It declined at both sites as winter approached and ice formed in early November. At these two sites there was little correlation between standing crop size and productivity ($r=0.608$ and $r=0.237$, $p=0.05$) whereas there was at the artificially shaded site ($r=0.961$, $p=0.05$). Shading also appeared to retard and delay standing crop and productivity peaks (Figure 62).

Expressing the productivity as a function of standing crop or as a photosynthetic index (mg C (mg chlorophyll $\underline{a}$)$^{-1}$ m^{-2} hr^{-1}) found the shore epilithic algae with the highest mean value while the lowest was occurred at the midstream site (Table 33).

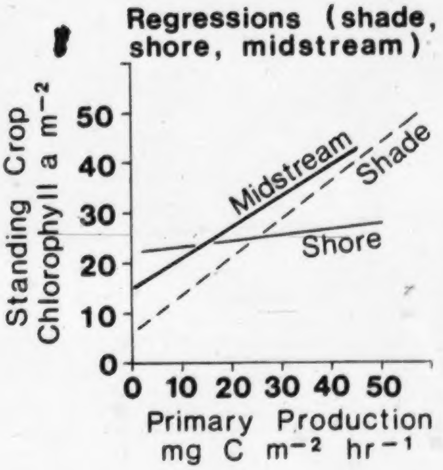
Figure 62.
Epilithic primary productivity, standing crops and linear regressions for shore, midstream and shaded midstream microhabitats in the Muskeg River during 1978.



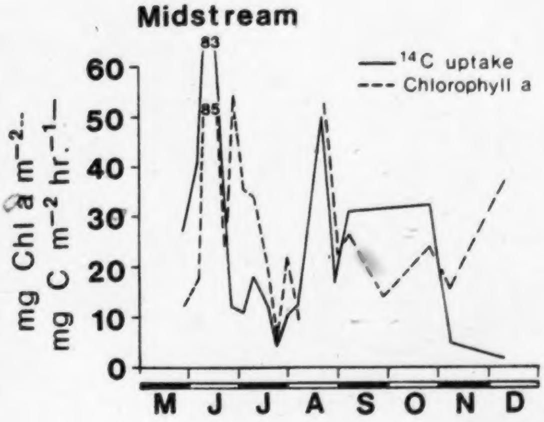
Shaded



Shore



Regressions (shade, shore, midstream)



Midstream

Table 33

Production, photosynthetic index and standing crops for the Muskeg River microhabitats during 1978

Microhabitat	Mean Primary Productivity $mg\ C\ m^{-2}\ hr^{-1}$	Mean Photosynthetic Index $mg\ C\ (mg\ Chl\ \underline{a})^{-1}\ m^{-2}\ hr^{-1}$	Mean Standing Crop $mg\ Chl\ \underline{a}\ m^{-2}$
Shore	22.9	0.86	26.6
Midstream	21.1	0.69	31.1
Midstream (shaded)	13.8	0.82	16.8

At the midstream shaded site epilithic standing crops were 56% smaller and productivity 60% smaller than at the unshaded site.

4.3.4.4 Substratum Comparison

As mentioned earlier naturally occurring bitumen in the Steepbank River supported an algal community, consisting primarily of Cyanophycean algae. Therefore standing crops and productivity were also compared between the epi-bituminous algae and the epilithic algae (Figure 63). Primary productivity associated with both limestone rock and bitumen remained similar June through early September of 1978; however, it dramatically increased on the rock substratum during late October when algal numbers (particularly diatoms) were also higher. Productivity declined on both substrata during ice formation in early November. Primary productivity ranged from 3.2 to 27.5 mg C m^{-2} hr^{-1} for limestone attached epithilic algae and 0.18 to 11.7 mg C m^{-2} hr^{-1} for bitumen. Cyanophycean algae were numerically dominant for both substrata accounting for 86 to 99% of the limestone epilithon and 73 to 99% of the oilsand benthos.

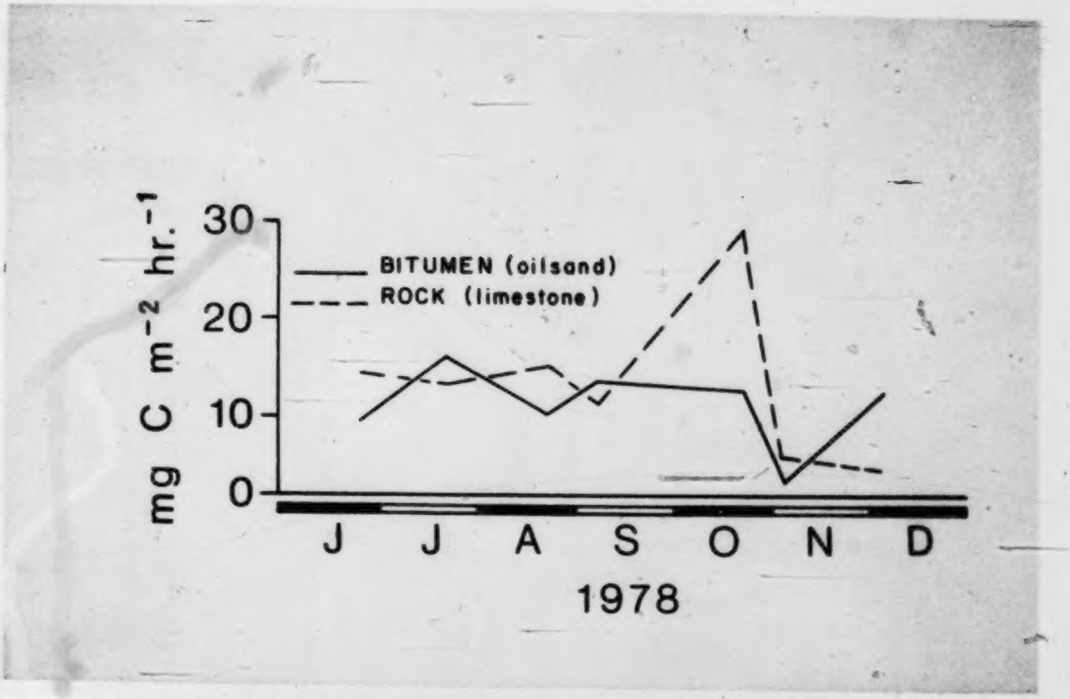


Figure 63 (a) Epilithic productivity on oilsand and rock substratum.

Figure 63 (b) Photograph of the substratum found in the Steepbank River.

Microalgae were more abundant on the limestone while macroalgae particularly Nostoc commune were more abundant upon the oilsand substrate. This investigation provided evidence that primary productivity during 1978 was 22% higher for epilithic algae or limestone than those or the bitumen, and the difference was statistically significant for p=0.05.

4.3.4.5 Diurnal Experiment

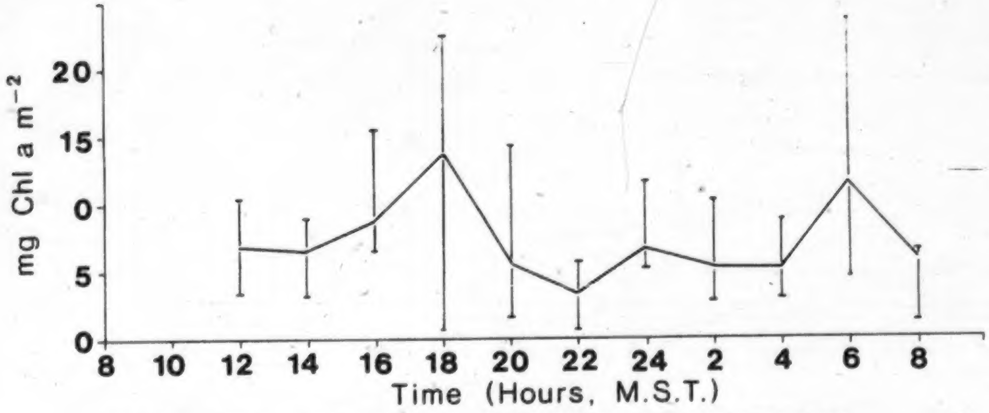
There have been few studies of diurnal productivity for northern latitudes (Murphy, 1984; Ilmavita, 1977). Therefore, one such experiment was conducted over the period July 28/29, 1979. The results are presented in figure 64.

Epilithic algal productivity was highest during the midday period (1200-1600 hr), and minimal during 0200-0600 hrs. Moreover, during the mid-day productivity and bicarbonate alkalinity were inversely related; alkalinity ranged from 3.4 to 3.7 meq L^{-1} with the minimum extending until 2000 hrs despite ^{14}C uptake declines from 42.2 mg C m^{-2} hr^{-1} (midday) to 1.3 mg C m^{-2} hr^{-1} at 2000 hrs. pH ranged from 6.6 to a maximum of 7.2 by 1400 hours. Diurnal fluctuations of pH and bicarbonate attributed to physical and biotic factors were in fact minor compared to those reported for productive systems (Wetzel, 1975).

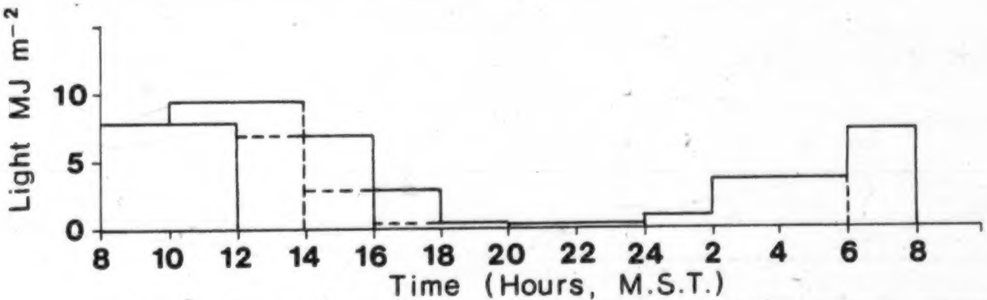
Temperatures in the Muskeg River were lowest at 0400 hrs (18^{o}C) just prior to sunrise and maximum during early evening 18-2000 hrs (19^{o}C).

Benthic algal standing crop estimates were also variable throughout the experiment. The range of standing crop estimates were higher during the early evening and morning. Simple linear regression indicated that

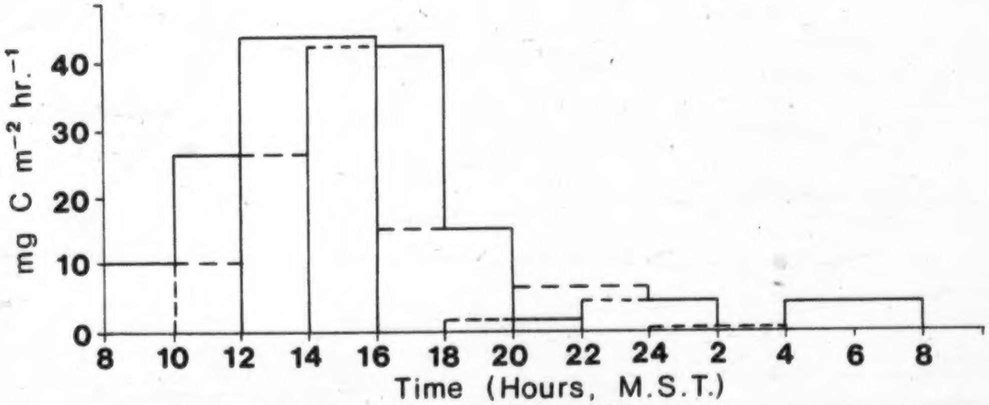
Figure 64.
Diurnal primary productivity, and standing crops for the Muskeg River during 1979.



MAXIMUM, MINIMUM AND MEAN EPILITHIC STANDING CROPS FOR EACH INCUBATION.



CUMULATIVE SOLAR RADIATION FOR JULY 28,29, 1979.



EPILITHIC ^{14}C UPTAKE DURING JULY 28, 29, 1979, FOR THE MUSKEG RIVER.

^{14}C uptake and chlorophyll a were highly correlated during this short term study ($r=.745$) ($p = < 0.05$). Photosynthetic efficiency reached a maximum of 5.01 mg C $^{m-2}$ hr^{-1} during 1200 - 1600 hours, the period of peak insolation (Figure 64). However ^{14}C uptake and insolation were in part, negatively correlated ($r-.397$, $p = 0.05$).

4.3.5 Temporal Nitrogen Fixation Changes

4.3.5.1 Epilithon

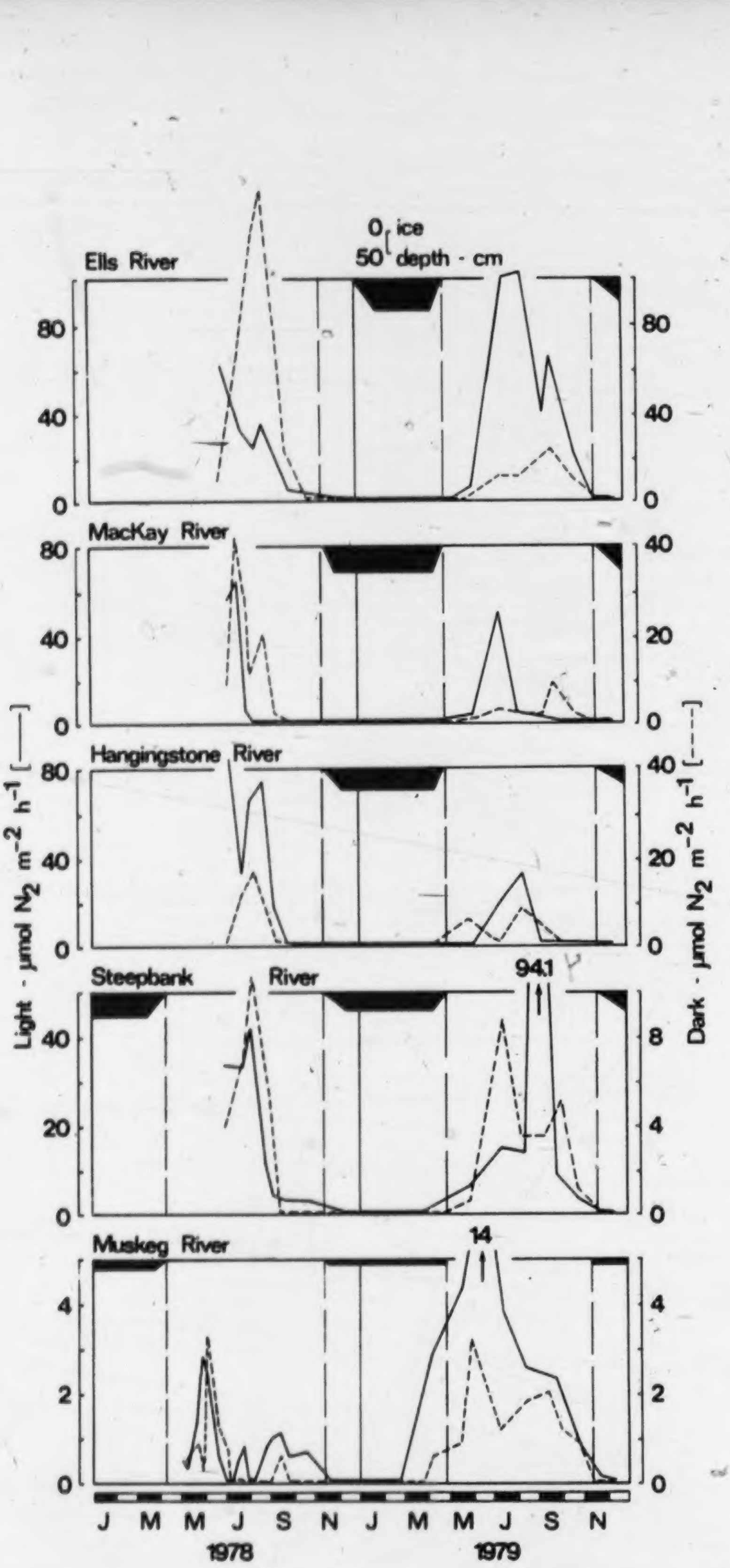
Temporal nitrogen fixation patterns were similar in all five rivers (Figure 65). Maxima occurred during the spring/summer period, but not always corresponding to the largest Cyanophycean populations. The dominant Cyanophycean species or potential algae capable of elemental nitrogen fixation indicated (Table 34) below were similar in all rivers.

Table 34

The dominant Cyanophycean algae coinciding
with the nitrogen fixation maxima in the five rivers

Species	River									
	Muskeg		Steepbank		Hangingstone		MacKay		Ells	
	1978	1979	1978	1979	1978	1979	1978	1979	1978	1979
Anabaena affinis	-	-	-	-	+	-	+	-	+	+
Calothrix braunii	+	+	-	+	+	+	+	+	+	+
C. breviarticulata	+	+	-	-	-	-	-	-	-	-
Lyngbya aerugineo-caerulea	+	+	+	+	+	+	+	+	+	+
Nostoc Spp.	-	-	+	+	+	-	-	+	+	+
Oscillatoria sp.	-	-	-	-	-	-	-	-	+	-
Phormidium sp.	+	+	+	+	-	-	-	-	-	-

Figure 65.
Epilithic nitrogen fixation in the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


0 ice
50 depth - cm
Ells River
MacKay River
Hangingstone River
Steepbank River
Muskeg River
94.1
14
Light - µmol N2 m-2 h-1 [——]
Dark - µmol N2 m-2 h-1 [- - -]
0
40
80
20
4
2
8
J
M
M
J
S
N
J
M
M
J
S
N
1978
1979

Nostoc spp. were particularly abundant in the Ells, MacKay, Steepbank and Hangingstone (only during 1978). The timing of peak nitrogen fixation varied among the rivers; moreover differences between the two years, and among the rivers also occurred with respect to both light and dark fixation rates. Dark nitrogen fixation rates although displaying similar temporal fluctuations as light fixation rates were sometimes greater especially during 1978 in the Ells River (Figure 65). At that time (fall) epilithic algal populations, which were dominated by *Nostoc commune*, had accummulated to a depth of 1 cm. The reverse occurred the following year when fall discharge in the Ells was significantly lower than observed during 1978. Light and dark fixation maxima also did not always coincide, for example during 1978 and 1979 in the Muskeg and Steepbank rivers (Figure 65).

Epilithic nitrogen fixation was consistently minimal during the winter (cold water) periods, therefore the five rivers were compared for both the entire study period and the open water period of each year (April - November, Table 35).

Table 35

The mean number of epilithic Cyanophycean algae over the entire study period, and the range of nitrogen fixation for the open water periods of 1978 and 1979.

River	Cyanophyta	Nitrogen Fixation			
	$\bar{x}$ cells $10^{10}m^{-2}$	u moles $N_2hr^{-1}m^{-2}$			
		Over Entire Period		Open Water 1978	
		Light	Dark	Light	Dark
Muskeg	1.78	0-14.30 $\bar{x}$ = 1.52	0-3.18 $\bar{x}$ = 0.65	0.01-2.83 $\bar{x}$ = 0.57	0.01-3.30 $\bar{x}$ = 0.57
Steepbank	1.45	0-31-94.10 $\bar{x}$ = 12.26	0.01-16.80 $\bar{x}$ = 2.26	0.41-41.50 $\bar{x}$ = 23.83	0.01-16.80 $\bar{x}$ = 6.68
MacKay	15.40	0.09-64.00 $\bar{x}$ = 8.72	0.86-42.00 $\bar{x}$ = 5.99	0.09-64.00 $\bar{x}$ = 17.48	0.86-42.00 $\bar{x}$ = 16.43
Hanging-stone	46.70	0-84.00 $\bar{x}$ = 17.2	0-17.00 $\bar{x}$ = 2.20	0-84.00 $\bar{x}$ = 39.40	0.10-17.00 $\bar{x}$ = 4.17
Ells	50.7	0.01-110.00 $\bar{x}$ = 27.14	0.39-143.00 $\bar{x}$ - 23.55	0.01-61.00 $\bar{x}$ = 21.60	0.39-143.00 $\bar{x}$ = 49.90

	Open Water 1979	
	Light	Dark
Muskeg	0.02-14.30 $\bar{x}$ = 3.62	0.04-3.18 $\bar{x}$ = 1.33
Steepbank	0.31-94.10 $\bar{x}$ = 17.93	0.33-8.5 $\bar{x}$ = 3.41
Mackay	1.02-49.00 $\bar{x}$ = 8.68	0.44-2.5 $\bar{x}$ = 1.53
Hangingstone	0.59-33.40 $\bar{x}$ = 11.38	0.11-8.8 $\bar{x}$ = 2.49
Ells	0.71-110.0 $\bar{x}$ = 56.19	0.53-21.9 $\bar{x}$ = 12.4

The Ells and Muskeg Rivers possessed the largest and smallest Cyanophycean populations and similarly the highest and lowest rates of nitrogen fixation respectively.

The data acquired through these investigations were employed to determine the relationship between epilithic nitrogen fixation and factors previously shown to affect fixation rates for each river and for all rivers combined. With the exception of temperature all other parameters were log transformed in order to yield a normally distributed data base.

Epilithic algal nitrogen fixation was consistently negatively correlated with ambient nitrate-nitrogen concentrations. Negative relationships also occurred for Cyanophyta numbers and nitrogen fixation in the Steepbank, Hangingstone and Ells Rivers where *Nostoc commune* were always observed; temperature was negatively correlated with nitrogen fixation in the Muskeg River. Interestingly, *Nostoc* spp. were very rare in the Muskeg River, while filamentous and colonial Cyanophytes were abundant.

Multiple linear regression was also performed to determine which of the parameters already outlined affected nitrogen fixation appreciably (Appendix 9). Among each of the rivers the primary variable affecting nitrogen fixation was ambient nitrate-nitrite nitrogen concentration. For all rivers combined however, the primary variable affecting nitrogen fixation was chlorophyll *a* followed closely by temperature and nitrate-nitrite nitrogen.

4.3.5.2 Microhabitat Differences

Nitrogen fixation by the epilithic algae was also measured at shore, midstream and artificially shaded midstream sites in the Muskeg

River (1978). Species composition was similar at the three sites but the dominant Cyanophycean algae differed (Table 36).

Table 36.

Dominant species, numbers and nitrogen fixation among three Muskeg River microhabitats during 1978

Site Muskeg River	Dominant cyanophycean algae	x cyanophycean Numbers Cells 10^{10} m^{-2}	Nitrogen Fixation Light u mol N_2	Dark m^{-2} hr^{-1}
Shore (15 cm depth)	*Lyngbya aerugineo-caerula* *Phormidium* sp (s) *Calothrix braunii*	1.48	0.40	0.13
Midstream	*Lyngbya-aerugineo-caerula* *Phormidium* sp (s) *Calothrix braunii*	1.70	0.63	0.38
Artificially Shaded	*Aphanothece nidulans* *Calothrix braunii* *Microcystis incerta*	1.27	0.15	0.07

Heterocystous and non-heterocystous filamentous species were similar at the shore ~~and midstream~~ sites. (ie. *Lyngbya*, *Phormidium*, *Calothrix*). Colonial (*Aphanothece*, *Microcystis*) and filamentous *Calothrix* forms were dominant under the artificial shade. At the shore and midstream sites Cyanophycean numbers fluctuated similarly but the June and September peaks were more pronounced at the latter site (figure 66). Under shade, numbers fluctuated far least with the maximum occurring in October. Mean numbers were highest at midstream and least under shade (Table 36). The differences in algal numbers were statistically different for shore vs midstream (p=.025), midstream vs shaded midstream (p=.005), and shore vs midstream (p=0.05).

Nitrogen fixation (both light and dark) was highest at the midstream (unshaded) site (Table 36) with pronounced June, July, and September peaks (Figure 66). Significant differences occurred between the midstream shaded and unshaded sites (p=0.005), and between the shore and unshaded midstream (p=0.05). The difference between the shore and shaded midstream epilithic nitrogen fixation was not statistically significant.

4.3.5.3 Substrata Comparison

As indicated earlier both limestone rocks and naturally occurring oilsand or bitumen supported an abundance of Cyanophycean algae in the Steepbank River, therefore nitrogen fixation was assayed for these substrata. Numbers peaked in July on both substrata (excluding *Nostoc Commune* (Figure 67). Afterwards numbers decreased rapidly upon the bitumen, and thereafter remained low. In contrast upon the limestone they remained high and even peaked again in October. The temporal fluctuations of *Nostoc* *commune* were identical upon both substrata.

Figure 66.
Epilithic nitrogen fixation and Cyanophycean numbers in shore (less than 15 cm depth) midstream and artificially shaded midstream communities of the Muskeg River during 1978.

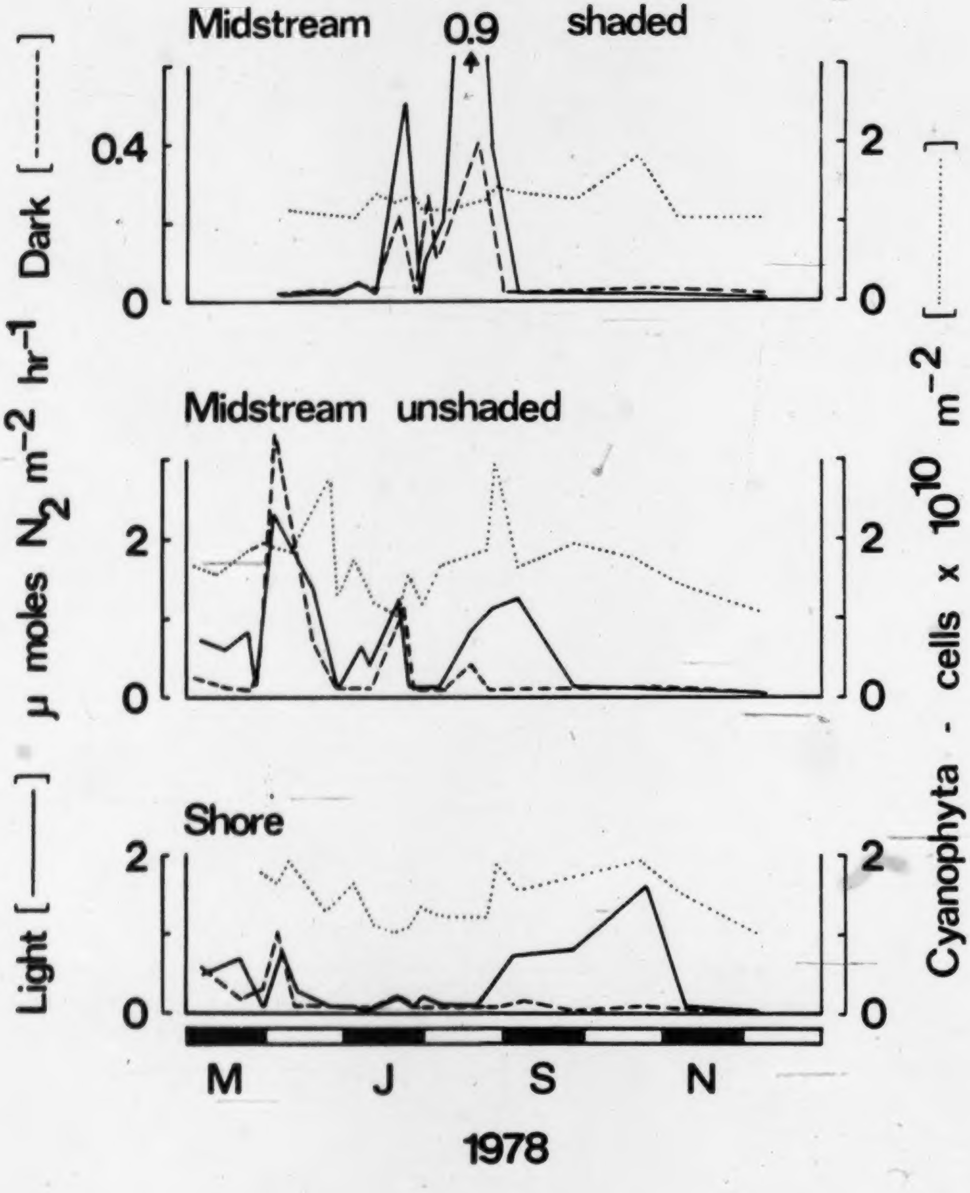
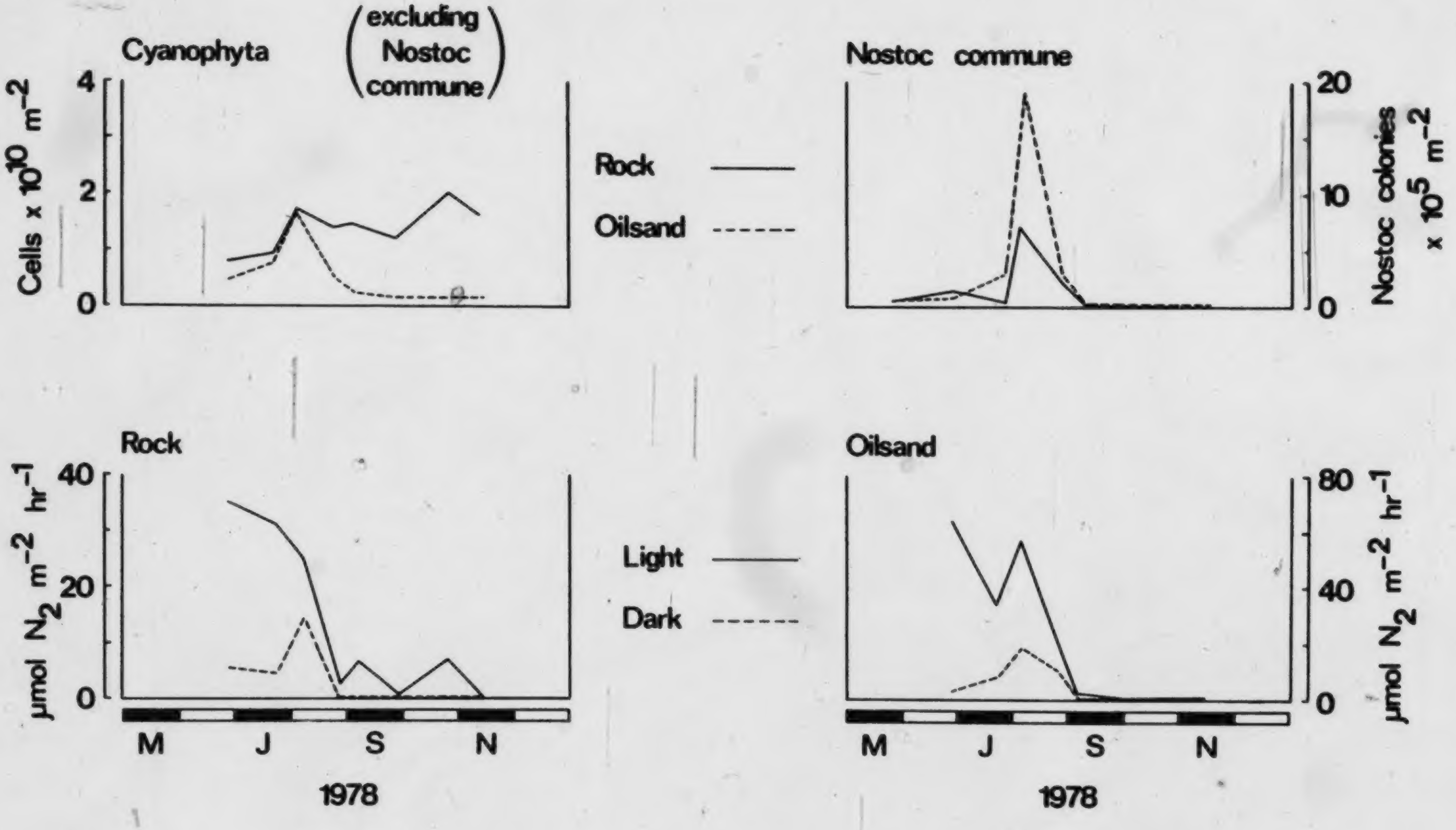

Midstream
0.9
shaded
Midstream unshaded
Shore
0.4
0
2
0
2
0
2
0
2
0
Light [——] µ moles N_2 m^{-2} hr^{-1} Dark [- - - -]
Cyanophyta - cells x 10^{10} m^{-2} [·······]
M
J
S
N
1978

Figure 67.
Nitrogen fixation and Cyanophycean algal numbers for epilithic algao attached to limestone rock and oilsand substratum in the Steepbank River.


Cyanophyta
(excluding Nostoc commune)
Cells x 10^{10} m^{-2}
4
2
0
Rock
Oilsand
Nostoc commune
Nostoc colonies x 10^5 m^{-2}
20
10
0
Rock
μmol N_2 m^{-2} hr^{-1}
40
20
0
Light
Dark
Oilsand
μmol N_2 m^{-2} hr^{-1}
80
40
0
M
J
S
N
1978
M
J
S
N
1978

However, Nostoc numbers were greatest upon the bitumen during the period of peak standing crop (Figure 67). The differences did not prove to be statistically significant. Statistically significant differences were however found for total Cyanophycean numbers ($p = 0.05$) between the two substrata. The following Table 37 indicates mean algal numbers and mean nitrogen fixation rates for the Steepbank River open water period of 1978 are presented in Table 35. Identical sampling dates and assay times were compared.

Table 37

Mean algal numbers and nitrogen fixation for oilsand and rock substrata in the Steepbank River during 1978

Substrata	Nostoc Commune Colonies $10^4 m^{-2}$	Total Cyanophycean No. cells $10^8 m^{-2}$	Nitrogen Fixation umol $N_2 m^{-2} hr^{-1}$ Light	Dark
Rock	13.6	156.1	13.4	3.3
Oilsand	32.0	60.0	20.1	5.1

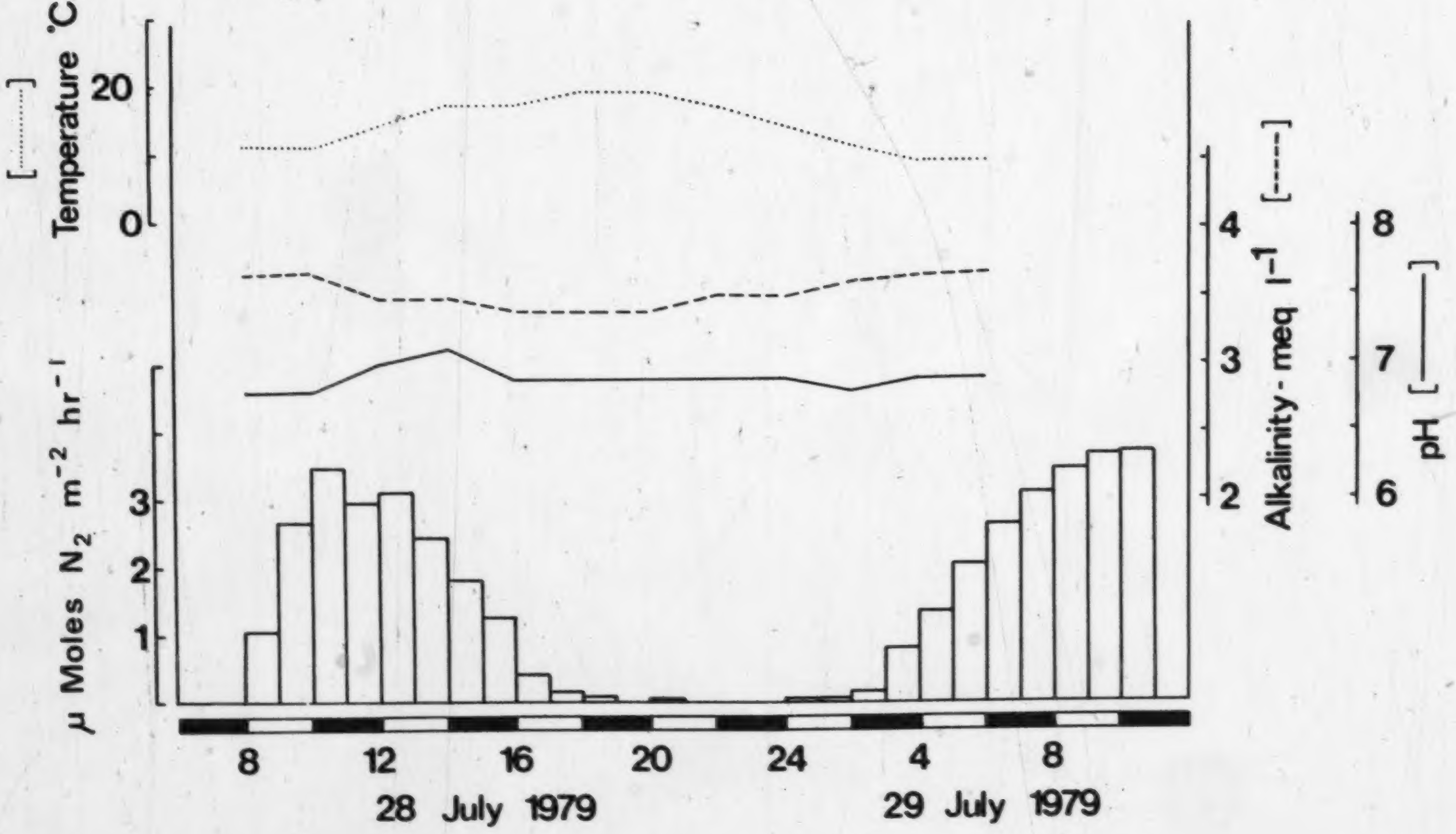
Nitrogen fixation although higher on average for epilithon attached to oilsand underwent similar temporal trends in the Steepbank River characterized by summer (July, August) peaks (Figure 67).

4.3.5.4 Diurnal Experiment

Diurnal epilithic nitrogen fixation was also assayed during July 28, 29, 1979, in the Muskeg River. On that date Lyngbya aerugineocaerula, Phormidium sp., Chaemosiphon incrustans and Calothrix braunii dominated almost exclusively.

Water temperature when the experiment began at 08:00 hours was 18°C increasing between 10:00 and 12:00 hours (Figure 68) to a maximum of 19°C between 18:00 and 20:00 hours, whereupon it declined to 10°C by

Figure 68.
The diurnal pattern of epilithic algal nitrogen fixation, pH, alkalinity and temperature for the Muskeg River during 1979.


Temperature °C [⋯⋯]
20
0
μ Moles N_2 m^{-2} hr^{-1}
3
2
1
Alkalinity - meq l^{-1} [-----]
4
3
2
pH [——]
8
7
6
8
12
16
20
24
4
8
28 July 1979
29 July 1979

04:00 hours during predawn of July 29. Bicarbonate alkalinity varied little while pH increased from 6.8 at 08:00 hours to a maximum of 7.2 at 14:00 hours before decreasing to, and remaining at 6.9 (except for a decline at 02:00 hours (Figure 68). Incident irradiance was greatest between 10:00 and 11:00 hours on both July 28 and 29.

During the first incubation period (08:00 to 13:00 hrs.) light fixation was high (2.85 umol of N_2 $m^{-2}hr^{-1}$) (Figure 68). It decreased slightly between 13:00 and 18:00 hours and more sharply between 18:00 and 23:00 hours to 1.15 umol N_2 $m^{-2}hr^{-1}$. This followed by an abrupt increase corresponding to an increase in irradiance levels as dawn drew into early morning. In fact the highest fixation rate of 3.15 umol. N_2 $m^{-2}hr^{-1}$ occurred during the morning period. Afterwards rates decreased even though irradiance levels continued increasing. Less variability was observed for dark fixation rates (Figure 68).

Nitrogen fixation efficiency (umol N_2 mg^{-1} Chl a $m^{-2}hr^{-1}$) in clear glass bottles was maximum between 18:00 and 23:00 hours whereas dark bottle efficiency was highest between 23:00 and 04:00 hours (Figure 68).

4.3.6 Cluster and Principal Components Analysis

Cluster and principal components analyses was applied to a set of fourteen physical, chemical and biological attributes of the five rivers under investigation. A total of 92 cases were included in the program analysis for the Muskeg, Steepbank, Hangingstone, Ells and MacKay, 1978 and 1979 data pool. The first three component eigenvalues greater than 1.5 were utilized for ecological interpretation of the similarities and differences among the rivers. Ibaney (1983) and Lengendre and Legendre (1979) recommended the use of eigenvalues greater than 1. Since they usually explain the majority of the data variance within the first two or three vectors (de Emiliani and Depestris, 1982, Charlton, Hamilton, Cross, 1985).

Table 38

Eigenvector coefficients, eigenvalues, total variance and cummulative variance accounted for by the first five components

Eigenvector	I	II	III	IV	V
Coefficients					
Prod. (^{14}C uptake)	.104	0.169	-0.164	-0.490	-0.102
Std. Crp (Chl a)	.023	-0.241	-0.211	-0.129	.620
Temperature	.332	-0.173	.426	-0.035	-0.082
Discharge	.232	.528	-0.138	-0.025	.132
Velocity	.273	.513	-0.160	.007	.161
Nitrogen	-0.136	.260	.297	.402	.164
Phosphorus	-0.188	-0.097	-0.257	.583	-0.078
Silica	-0.463	.008	-0.011	-0.006	.244
pH	.292	-0.209	.426	.252	.070
T. Alkalinity	-0.454	-0.188	.052	-0.077	-0.047
N-Fixation	.288	-0.291	.087	.183	.212
Nmbs (Chlorophyta)	.191	-0.231	-0.216	-0.022	.398
Nmbs (Cyanophyta)	.210	-0.135	-0.306	.062	-0.502
Nmbs (Bacillariophyta)	.167	-0.173	-0.466	.364	-0.028
Eigenvalue	3.21	2.32	1.74	1.28	1.11
Total Variance (%)	22.93	16.58	12.39	9.16	7.96
Total Variance (cummulative %)	22.93	39.51	51.90	61.06	69.02

The first three principal components accounted for nearly 52% of the total data pool variance (Table 38) and can be interpreted as representing the lotic seasonal influence. The first component with 22.93% of the variance can be interpreted as representing the spate (spring/fall) influence. This finding emerges from the highly positive weight exerted by the contributions of river temperature, pH, nitrogen fixation, velocity and discharge. During the spring and fall periods, North Eastern Alberta river temperatures and nitrogen fixation are low while velocity, discharge and pH are high, indicating that high discharge, velocity and low temperature may stimulate biological related pH increases by non-nitrogen fixers such as diatoms. Moreover, high negative scores for vector I were attributed to the variable silica, alkalinity, nitrogen and phosphorous.

The second component with 16.58% of the variance can be interpreted as representing the lotic influence. This finding emerges from the highly positive weight exerted by the contributions of lotic discharge, velocity, nitrogen and the negative scores (Table 38) for nitrogen fixation, algal standing crop and numbers of Chlorophyta. The climatological factors which increase discharge and velocity also increase lotic nitrogen and silica concentrations. Conversely high discharge and velocity disrupt the benthic algal communities reducing nitrogen fixation, chlorophyll a and particularily the numbers of Chlorophycean algae.

The third component explained 12.39% of the variance and can be interpreted again as the nutrient influence. Temperature, pH, and nitrogen variables provided a significant contribution to the eigenvector. Diatoms, blue green algal numbers and phosphorus provided negative scores (Table 43).

Four major clusters were defined using the same data subjected to principal components analysis. Cluster analysis placed the data from all the rivers (1978/79) into groups (clusters) based upon similarities among the fourteen physical, chemical and biological values included in the program. This technique consisted of calculating a similarily matrix between samples using the squared Euclidean Distance Method (Sneath and Sokal, 1973). Clustering was then performed by using Ward's Hierarchical Fusion Method (Ward 1963).

The nature of the three vectors is illustrated in Figure 69 and the distribution of clusters along vectors I, II and III is presented in figure 70.

Cluster 3 consisted of 15 cases where the Muskeg, Steepbank, MacKay and 1979 Hangingstone winter data (16 Nov. - 16 April) grouped together. Silica, total alkalinity, phosphorous and nitrogen were the principal components explaining this cluster. Within this cluster the mean values for the principal components were 8.1 mg L^{-1}, 4.3 meq L^{-1}, 0.08 mg L^{-1}, and 0.21 mg L^{-1} respectively.

Cluster 2 consisted of 19 cases which were skewed to the positive side of vector II. Discharge, velocity, nitrogen and silica were the most important components defining this cluster. The mean values were 22.67 $m^{-3}s^{-1}$, 0.98 cms^{-1}, .30 mg L^{-1}, and 4.6 mg L^{-1} respectively. Cluster 2 consisted of spring (17 April - 30 June) and fall (20 Aug. - 15 Nov) data (Figure 69 and 70) from the Muskeg, Steepbank, fall/78 Hangingstone, MacKay and spring/79 Ells. Hence cluster 2 emphasizes the similarity among the Muskeg, Steepbank, and MacKay Rivers during the spring and fall when spates occur.

Cluster 4 was widely divided among the negative sides of all except vector I. Consisting of 17 cases (Figure 70) cluster 4 contained Ells and Hangingstone data from all seasons and MacKay River (fall/winter). Four of the 17 cases represented summer data. Cluster 4 provides evidence that although the Ells, Hangingstone and MacKay (fall/winter) Rivers are dissimilar with respect to biotic communities, temperature, pH and nitrogen as well as nitrogen fixation are similar. Cluster four contains data having the greatest numbers of benthic algae an average temperature of 7.5°C; pH of 7.4 and nitrogen .18 mg L^{-1}. Indeed this cluster provides evidence of the physico-chemical factors which are particularly beneficial to benthic algal community development.

Cluster 1 consisted of 41 cases (Figure 69, 70) which were skewed from median position to positive along vectors I and III. This grouping includes data from all rivers particularily for the spring/summer seasons. Cluster 1 contains data having the highest average temperature (15.1°C), the highest pH (7.9), an average discharge of 47 m^3s^{-1}, and velocity of .37 cms^{-1}. Cluster one provides evidence that the five rivers examined during this study are similar with respect to a few physical and chemical characteristics during the summer, and these factors are the primary components explaining their particular limnology.

Figure 69.
The relative location of clusters I, II, and III
and their principal components.

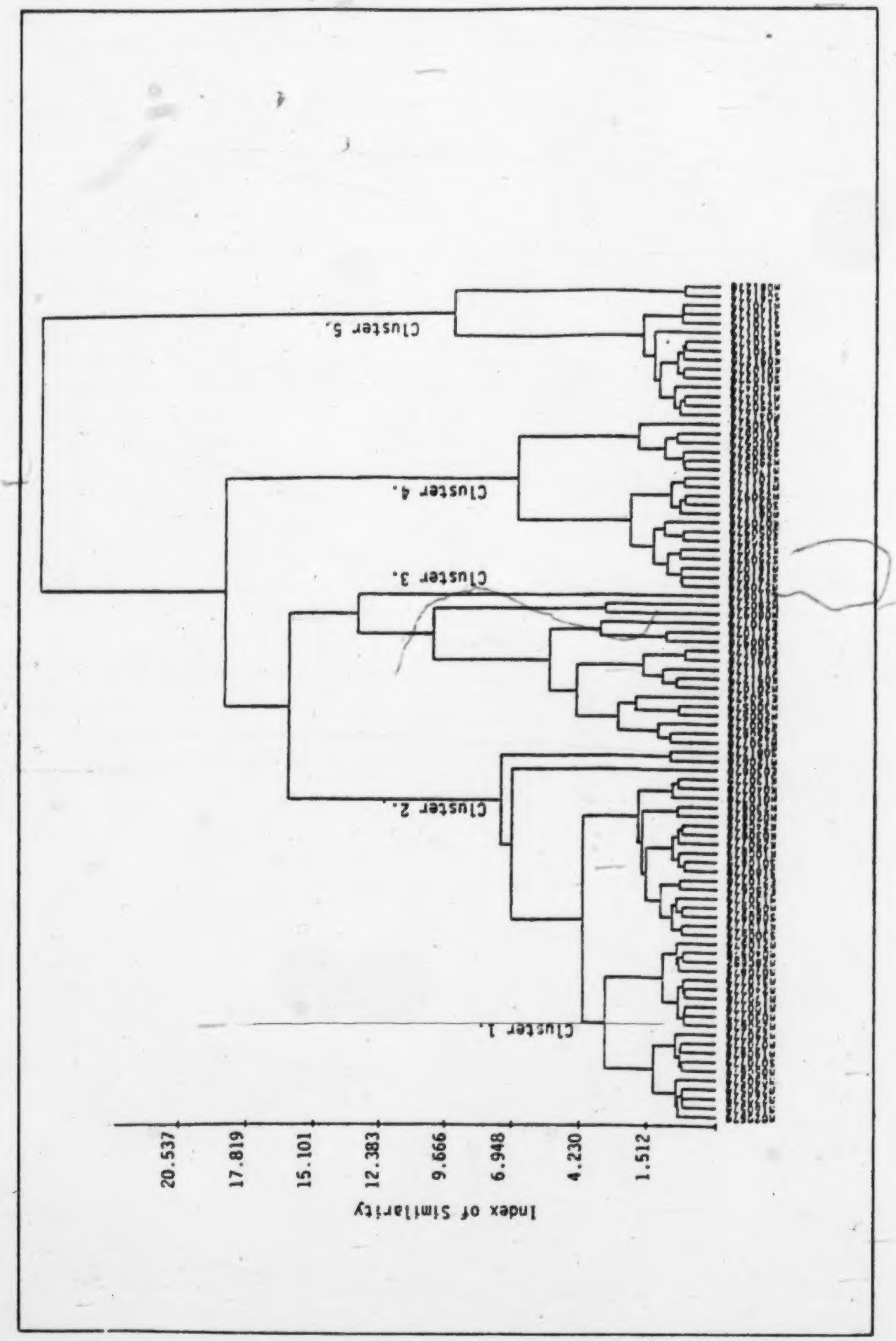
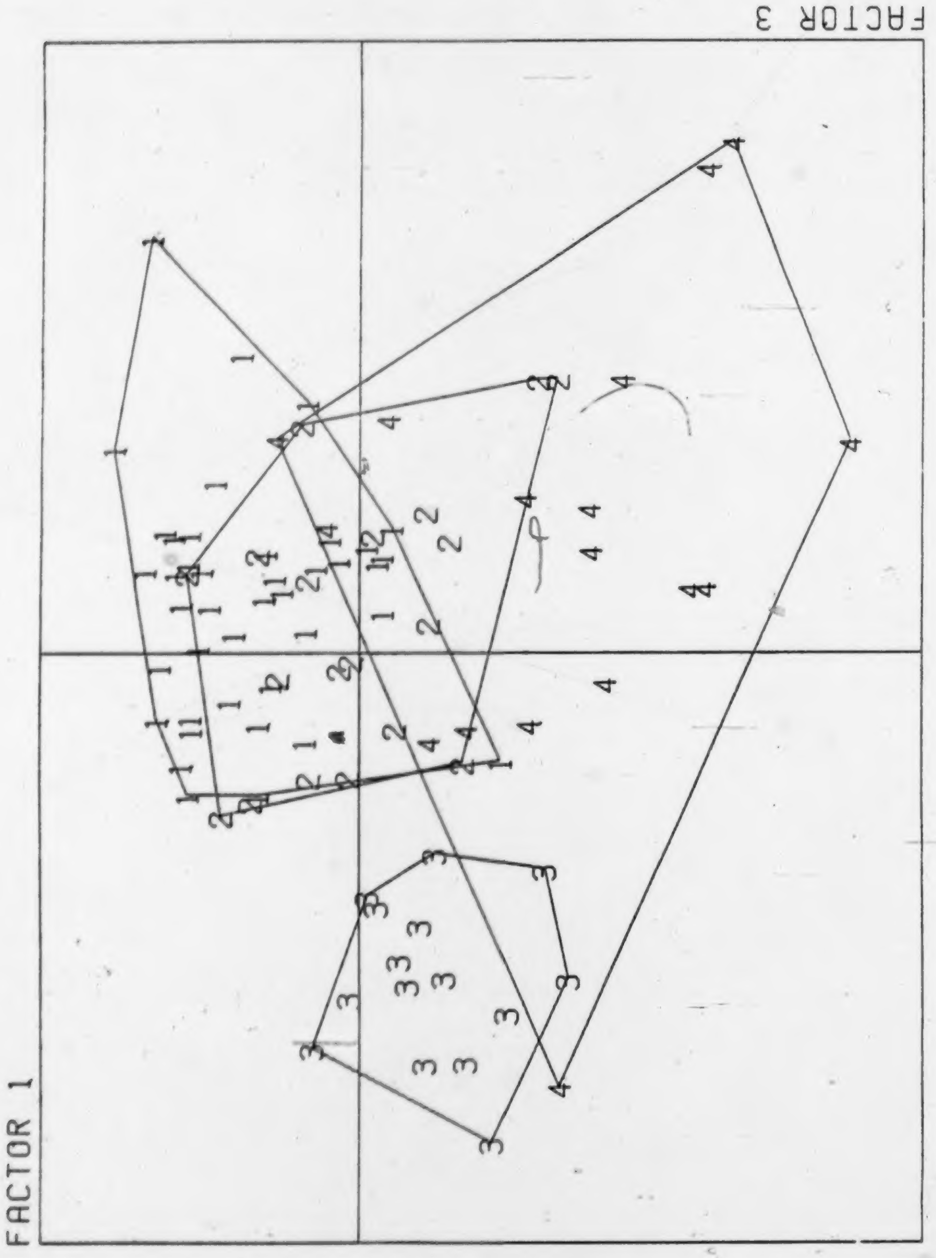

Index of Similarity
20.537
17.819
15.101
12.383
9.666
6.948
4.230
1.512
Cluster 1.
Cluster 2.
Cluster 3.
Cluster 4.
Cluster 5.

Figure 70.
The relative location of the first four clusters derived for the Ells, MacKay, Hangingstone, Steepbank and Muskeg rivers.


FACTOR 1
FACTOR 3
1
2
3
4

5. Discussion

5.1 Longitudinal Characteristics

Rivers occurring in the oil sands region of northeastern Alberta are atypical at their origin compared to the numerous descriptions quoted in Whitton (1975). The five rivers are not characterized by swift currents, steep gradients and pronounced erosion at their source. They originate in Muskeg, except for the Ells River which emerges from the Gardiner Lakes. The Muskeg, Steepbank, Hangingstone, and MacKay are slow flowing, meandering creeks with predominantly an organic substratum at their origin. Evidence of any erosion did not appear until the middle to lower reaches of all rivers. Haaslam, (1978) reported that channel size, width and depth generally increase in a downstream direction, in this respect these rivers are typical except for the Ells which was considerably wider in the upper reach.

Calcium was the major cation in all but the MacKay River where sodium was the most abundant. A consistent pattern emerged with respect to major anions whether the results were expressed as mg or meq l^{-1} with $HCO_3^- > SO_4^= > Cl^-$ in all but the Muskeg River. Here chloride replaced sulphate mainly due to the high concentrations originating from the catchment area sediments or ground waters. Schwartz (1979) reported that 12 to 40% of the Muskeg River stream flow during late spring, summer and autumn comprises ground waters derived from a watertable situated at a depth of 0.5 to 3.5 meters. This factor contributes to increasing ionic concentration in a downstream direction, particularly chloride. Nothing is known about the ground water regimes of the other four rivers. However, least effect would undoubtedly be found in the Ells River.

Several algae were cosmopolitan, being found in all rivers (e.g. *Lyngbya aerugieo-caerulea*, *Chamydomonas* sp., *Chlorella vulgaris*, *Achnanthes lanceolata*, *Cocconeis pediculus*, *Cocconeis placentula*, *Cyclotella meneghiniana*, *Cymbella ventricosa*, *Epithemia argus*, *Fragilaria capucina*, *Gomphonema lanceolatum*, *Gomphonema olivaceum*, *Navicula cryptocephala*, *Nitzschia palea*, and *Synedra ulna*). All the cosmopolitan algae formed a dominant population at, at least one site in each river, except *Epithemia argus*. Only *Lyngbya aerugineo-caerula* and *Cocconeis placentula* did so in all rivers. The former species is tolerant of both hard water and dystrophic conditions, (Prescott, 1962); the latter prefers moderately alkaline waters (pH 7-9), unpolluted waters, (Schoeman,1973). Some species had very restricted distributions being found in only one river. For example, *Gomphosphaeria lacustris* v. *compacta*, *Crucigenia quadrata*, *Cryptomonas erosa*, *Achnanthes* sp., *Cymbella turgida*, *Eunotia lunaris*, *Fragilaria leptostauron*, *Gomphonema acuminatum* v. *coronata*, *Gomphonema ventricosum*, *Navicula gracilis*, *Pinnularia mesolepta*, and *Tabellaria fenestrata* were found only in the Muskeg River; *Hyalotheca* sp., *Pediastrum biradiatum*, *Gomphonema gracile*, and *Nitzschia hantzschiana* were confined to the Steepbank River; *Microspora pachyderma*, *Asterionella formosa*, *Cyclotella comta*, *Cyclotella kutzingianum*, *Diatoma elongatum*, *Diatoma vulgare* v. *ovalis*, *Fragilaria construens*, *Fragilaria construens* v. *binodis*, *Navicula minima* v. *atomoides*, and *Stephanodiscus astraea* were confined to the Ells River; *Pediastrum boryanum* was confined to the Hangingstone River; and to the MacKay River were confined *Chroococcus limneticus*, *Gomphosphaeria aponina*, *Oscillatoria amphibia*, *Chlorella ellipsoidea*, *Gloecystis gigas*, *Oedogonium* sp., *Pediastrum biradiatum* v. *emarginatum* f. *convexum*,

Scenedesmus acutiformis, Scenedesmus quadricauda, Sphaerocystis schroeteri, Sphaeroplea annulina, Ulothrix sp., Dinobryon sertularia, Mallomonas sp., Cymbella lanceolata, Eunotia pectinalis v. minor, Eunotia valida, Hantzschia amphioxys, Neidium affine, Neidium affine v. amphirhynchus, Stauroneis anceps, and Surirella ovalis.

In general, these rivers were dominated by Cyanophycean algae except for the MacKay River. In fact, this group accounted for 97.3% of the total epilithic community in the Steepbank River. The dominant species were Lyngbya aerugineo-caerula, Anabaena affinis, Calothrix braunii, and Nostoc spp. In the Muskeg River blue green algae accounted for 87.4% with Lyngbya aerugineo-caerulea most important compared to Anabaena affinis and Calothrix braunii. On average, Chlorophycean algae only accounted for 8.1% although at some sites some accounted for as much as 41.1% (e.g. site 4 - Cladophora glomerata). Diatoms accounted for only 4.3%. Cyanophycean algae were less important in the Ells River (75.4%). Here diatoms were important (21.7%). Again Lyngbya aerugineo-caerulea was the important Cyanophyte. A variety of diatoms were important depending upon the site but included Achnanthes lanceolata, Cymbella sinuata, Cymbella ventricosa, Diatoma vulgare, Diatoma vulgare v. grandis, Gomphonema olivaceum, Cocconeis placentula, Cyclotella kutzingianum, Fragilaria pinnata, Nitzschia palea, Nitzschia recta, Navicula minima v. atomoides, and Cyclotella meneghiniana. Diatoms were even more important compared to blue green algae in the Hangingstone River (37.0 and 47.0% respectively). Lyngbya lerugineo-caerulea, Anabaena affinis and Oscillatoria sp. were the important blue green algae and Navicula graciloides, Achnanthes lanceolata, Epithemia sorex, Cocconeis placentula and Synedra ulna comprised the important diatoms.

Overall, Chlorophycean and Rhodophycean algae were minor components (11.9 and 3.3% respectively) even though, for example *Batrachospermum vagum* accounted for 23.4% at site 3 of the Hangingstone River. The MacKay River was the most diverse and on average all algae groups contributed at least 2.0%. Chlorophycean algae were the most important (58.1%). Several species contributed with none being absolutely dominant (e.g. *Chlorella vulgaris*, *Chlamydomonas* spp.), Cryptophycean algae (*Cryptomonas ovata* and *Rhodomonas minutum*) comprised 10.2%, Cyanophycean algae (mainly *Lyngbya aerugineo-caerulea*, *Oscillatoria* sp., and *Anabaena affinis*), 8.3%; diatoms (*Pinnularia gibba*, *Navicula cryptocephala*, *Fragilaria vaucheriae*, *Cocconeis pediculus*, *Epithemia sorex*) 6.3%; Chrysophyta and Euglenophyta both 5.1%; and Pyrrophyta and Rhodophyta 2.5% and 2.0% respectively.

Chlorophyll *a* analyses provided evidence that the five rivers supported higher standing crops in the upper and middle reaches. Crowther, (1980) reported similar findings for benthic invertebrates. Hence the rivers investigated during this study are more productive in the upper and/or middle reaches where the relative contribution of detritus is also highest. High middle reach algal standing crops were associated with an opening of the forest canopy (which allowed more light to reach the substratum) and a predominance of rock substratum. Rivers in North-Eastern Alberta therefore exhibit a high degree of physical, chemical and biotic longitudinal variation which probably functions to maintain lotic system stability.

5.1.1 Epilithic Algal Sampling Technique Comparison

An investigation of three different sampling techniques applied to four microhabitats throughout this study of the Muskeg River provided further evidence of the extremely heterogeneous nature of epilithic algal communities. Well defined differences among standing crop estimates were found as shore, midstream, riffle and artificially shaded microhabitats were compared. The differences were more evident on a daily or weekly basis than for long term studies. The various sampling techniques provided evidence of the complex variability which occurs in rivers both temporally and spatially. No particular technique was significantly different as a method for estimating epilithic algal standing crop; however, the differences with respect to time and equipment were profound. The quadrat technique was extremely monotonous and very time-consuming. The single rock brush technique was less demanding than the quadrat; however, the need to transport rocks from remote areas for area determination is hardly economical. The scrape technique on the other hand was efficient, rapid and required a minimum of sampling equipment. It is particularly useful for remote areas and specifically when a limited space is available in which to transport supplies (i.e. a helicopter). All of the sampling techniques are potentially biased by the collector during substrate collection and selection of the scraping site on the rock surface. Moreover, the presence of macro-algae i.e. Cladophora spp. and Nostoc spp. clog pipettes during the subsampling further introducing potential error. Thus it would appear that any of these techniques is useful for long term studies. Care, must however be taken to survey all microhabitats and particularly during the periods of abundant epilithic community development.

5.2 Seasonal Patterns or Temporal Changes

5.2.1 Physical and Chemical Changes

5.2.1.1 Temperature

Throughout the five rivers water temperatures were lowest during the period of ice cover (generally November through April) and the highest during late July or early August. Boon and Shires (1976) indicated that flow rate, however small, maintains river temperatures in northeast England, and also temporary flow pools may contribute to increased river water temperature. Temporary pools were more abundant throughout the upper reaches of both the Muskeg and MacKay Rivers (Charlton, Hickman, Jenkerson 1981) and may account for the greater mean temperatures in these rivers. Water temperatures annually declined with increasing September discharge and increased at the onset of spring breakup and increased discharge, illustrating the role of runoff and radiation in the maintenance of water temperatures. There was no evidence suggesting that increasing discharge during late winter resulted in marked temperature increases prior to the breakup; which agrees with the findings of Langford (1970). Thus, direct radiation and re-radiation from the streambed are the two principle factors contributing to the observed temperatures.

5.2.1.2 Discharge

Discharge (current speed) exerts a profound mechanical force in lotic systems which is both destructive (McIntire, 1966) and beneficial (Ruttner 1960) to organisms. It affects both species composition and morphology (McIntire, 1966) as well as biomass accumulation (Reisen et al (1970). In addition to the physical forces exerted by discharge, its increase causes dilution of ions and nutrients thus the nutrient status of water.

Discharge peaks occurred bi-annually in April/May and September/October in all five rivers. High spring discharge is attributed to runoff and snowmelt while high fall discharge is attributed to runoff increase resulting from a reduction of the deciduous plant water uptake throughout each basin. The fall and spring spates in the Hangingstone and Muskeg Rivers in fact were of comparable size. Spring spates were larger than fall ones in the remaining rivers. The MacKay which drains the largest area also possessed on average the greatest discharge rates.

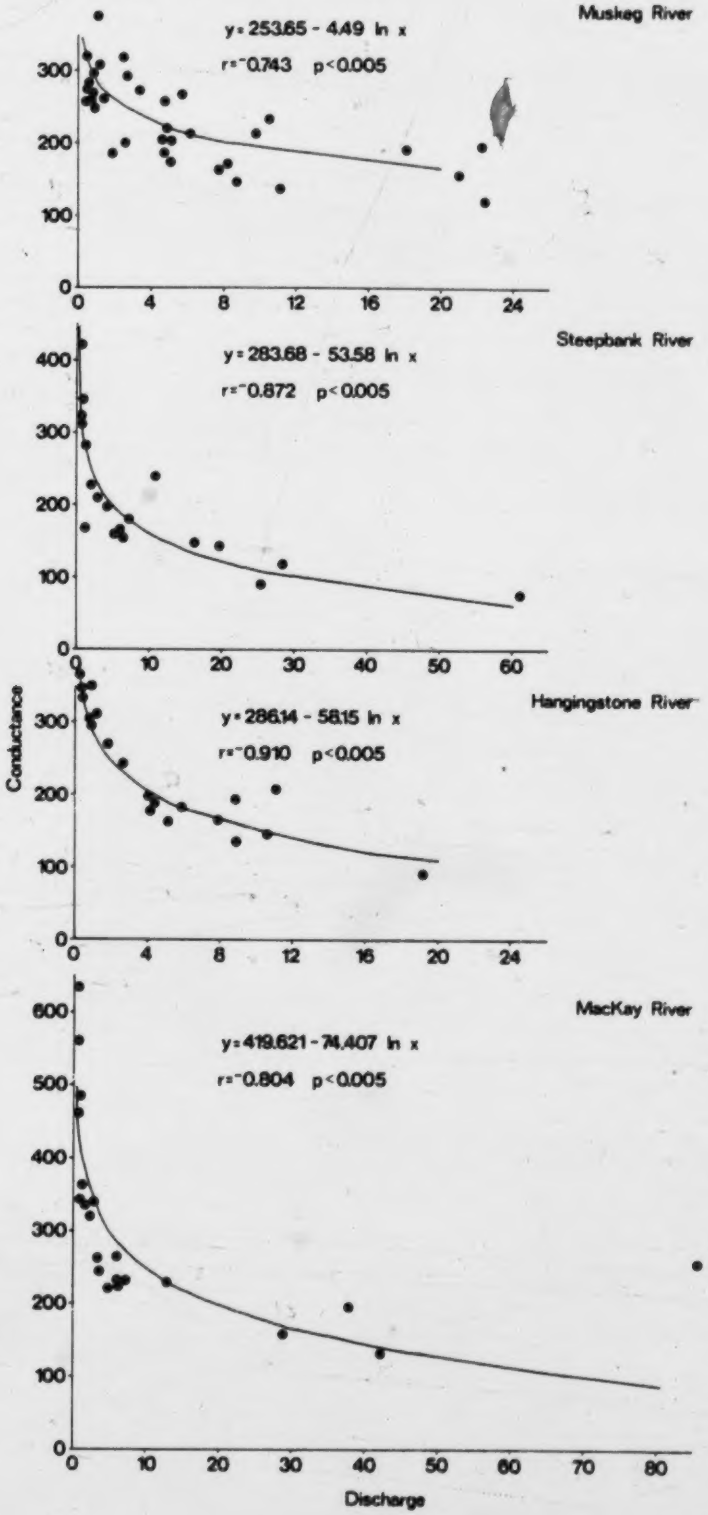
5.2.1.3 Specific Conductance

High winter specific conductance was characteristic of all rivers, except the lake-fed Ells River. Schwartz (1979) attributed high winter conductivity to the increasing role played by groundwater inputs in relation to river discharge. Conversely during periods of ascending discharge, conductance decreased due to dilution effects. Specific conductance was negatively correlated in a logarithmic manner with discharge rates in all but the Ells River (Figure 71, Appendix 10). The headwater lakes of the Ells had a buffering effect upon discharge rates which maintained specific conductance within a very narrow range and while conductance among all the rivers increased in a downstream direction the amplitude and values remained lower throughout the Ells. Thus the origin of a river plays a major role with respect to specific conductance.

5.2.1.4 Calcium

Calcium concentrations in all of the rivers investigated were highest during the winter period. Schwartz (1979) indicated that calcium is one of the dominant cations found in groundwater examined throughout the Muskeg River catchment area. Calcium, like conductance

Figure 71.
Relationships between conductance
and discharge.


Muskeg River
y = 253.65 - 4.49 ln x
r = ⁻0.743 p < 0.005
Steepbank River
y = 283.68 - 53.58 ln x
r = ⁻0.872 p < 0.005
Hangingstone River
y = 286.14 - 58.15 ln x
r = ⁻0.910 p < 0.005
MacKay River
y = 419.621 - 74.407 ln x
r = ⁻0.804 p < 0.005
Conductance
Discharge
0
100
200
300
400
500
600
0
4
8
12
16
20
24
10
20
30
40
50
60
70
80

was negatively correlated in a logarithmic manner with discharge rates in all but the Ells River (Appendix 10). Thus it would appear that groundwater again plays a major role with respect to maintaining winter discharge among the Muskeg, Steeplebank, Hangingstone and MacKay Rivers. Calcium among all the rivers averaged 18.9 mg L^{-1}. This represents a value less than that reported for European rivers (i.e. 31 mg L^{-1}) as well as North American rivers (i.e. 21 mg L^{-1}) (Whitton, 1975). Calcium concentrations excluding the Ells River were however similar to those reported for North America (i.e. 20.5 mg L^{-1}).

5.2.1.5 Sodium

Sodium was also significantly correlated with discharge among all five rivers. Temporal fluctuations were however irregular in all but the Ells River. Neill and Evans (1979) indicated that sodium increases associated with spring thaw are derived from surficial runoff and lake contributions. High winter values are undoubtedly derived from groundwater sources. Wetzel (1975), indicated that sodium concentrations vary little seasonally in lakes due to the conservative nature of this ion, hence sodium concentrations fluctuate little in the Ells River which originates as a lake.

On a worldwide basis lotic sodium is highly variable. European rivers average 5.4 mg L^{-1}, North American rivers average 9 mg L^{-1} Whitton (1975). With the exception of the Ells River the average sodium concentration among these lotic systems is 24.6 mg L^{-1}. High values for this region are possibly related to considerable subsurface groundwater flow (Neill and Evans, 1979) which is extremely high in chloride (i.e. 10,000 mg L^{-1}) and total dissolved solids (19,000 mg L^{-1}) (Smith, 1979).

5.2.1.6. Potassium

With the exception of the Hangingstone River potassium concentrations were unrelated to discharge. In the Hangingstone River the relationship was linear (Appendix 10). Potassium undoubtedly enters these rivers in surface runoff being mobilized in particulate form or leached from the soils during the melting of the snow as well as periods of high rainfall. This can easily occur during the summer months because 50 to 75% of the annual rainfall occurs during this period, (Smith, 1979). Potassium concentrations also fluctuated most widely during 1978 (spring) coincident with above average rainfall further evidencing surface runoff mobilization.

Potassium concentrations among the five rivers averaged 1.2 mg L^{-1} with the highest occuring in the Steepbank. The average among the North Eastern Alberta rivers was lower than average values indicated by (Whitton, 1975) for European rivers (1.7 mg L^{-1}) and North American rivers (1.4 mg L^{-1}).

5.2.1.7. Magnesium

Calcium, magnesium and sodium were the dominant cations found in Muskeg River basin groundwater respectively (Schwartz, 1979). Magnesium concentrations in particular were highly correlated with discharge for all the rivers. Lotic concentrations were also particularly high during the winter months in all rivers except the Ells. Values fluctuated least in this river, averaging 3.6 mg L^{-1}. In the remaining rivers the concentration of magnesium averaged 8.0 mg L^{-1}, hence exceeding the mean values reported for European rivers (i.e. 5.6 mg L^{-1}) and North American rivers (i.e. 5.0 mg L^{-1}) (Whitton, 1975). Magnesium compounds are more soluble than their calcium counterparts and precipitate only at pH values greater than 10.

Since pH values were never this high in any of the rivers, summer fluctuations can only be attributed to algal uptake and allochthonous inputs. Moreover, magnesium adsorbs silicate at low SiO_2 concentrations (3.0 mg L^{-1}) thus affecting its availability to diatoms. SiO_2 values less than 3.0 mg L^{-1} were detected in all of the rivers studied.

5.2.1.8. Iron

Iron was not limiting in any of the rivers. Mean concentrations among the five rivers ranged from 0.08 mg L^{-1} (Ells) to .18 mg L^{-1} (Muskeg). The highest values were detected during the winter except in the Ells River. Due to the presence of high dissolved organic matter content originating in the bogs which constitute a greater portion of each river basin, biologically available iron is abundant. Sapiro (1957) in Wetzel (1975) indicated that high iron concentrations are associated with high levels of humic acids, tannic acids, Hem (1960) in Wetzel (1975) and other lignin derivatives. The iron complexes in fact impart an intense yellow-brown color of each river. Moreover, Wetzel (1975) indicated that the typical range of total iron found in oxygenated surface waters is about 0.05 to 0.2 mg L^{-1}. All of the rivers exceed this range due to the presence of bog waters within the river basins.

5.2.1.9. Manganese

Hutchinson (1957) indicated that manganese concentrations in aquatic systems are variable in relation to lithology and drainage patterns. Wetzel (1975) reported that values generally range between 0.1 and 0.85 mg L^{-1} and average 0.035 mg L^{-1}. Compared to these values manganese concentration in North Eastern Alberta rivers is higher than average (i.e. 0.14 mg L^{-1}). Sources of manganese accounting for elevated values include local alkaline soils Wetzel (1975), groundwater sources

(Schwartz, 1979) and drainage from the coniferous forests which occur within every drainage basin in the area (Wetzel, 1975).

Although manganese concentrations were high on average, values as low as 0.002 mg L^{-1} were detected in both the MacKay and Steepbank Rivers. Wetzel (1975) indicated that concentrations less than 0.05 mg L^{-1} are inhibitory to the development of green and blue-green algae in streams while strongly favoring diatom growth. Minimum concentrations were found in these lotic systems during the spring spate coincidentally with high relative percent contribution by diatoms in all rivers. Although values less than 0.05 mg L^{-1} were detected in all rivers during the study it did not entirely inhibit the blue-green algae perhaps due to the short duration of times in which concentrations were inhibitory.

5.2.1.10 Sulphate

The sources of sulphate ions in relation to lotic ecosystems include weathering of local rocks, soils, decomposition of organic matter, atmospheric precipitation and fall out from local industries. Whitton (1975) reported that North American Rivers average 20 mg L^{-1} and European Rivers 24 mg L^{-1} sulphate. In the MacKay River values were higher than the North American or European average. (ie 27.3 mg L^{-1}). Moreover sulphate was negatively correlated with discharge ($r = -0.806$, $p < 0.005$). Values were lower in the remaining rivers and similarly the relationship between discharge and sulphate was negative in the Steepbank ($r = -0.780$, $p < 0.005$) and Hangingstone ($r = -0.919$, $p < 0.005$). Sulphate and discharge were not related statistically in the Muskeg and Ells Rivers. Sulphate concentrations generally increased during the winter period in all rivers. Wetzel (1975) attributed this pattern to bacterial metabolism. It is likely however that groundwater inputs also influence winter concentrations. Spring and fall inputs attributed to runoff and precipitation are masked by the dilution effects of elevated discharge.

5.2.1.11 Chloride

While chloride influences general osmotic salinity balance and ion exchange, aquatic biota do not result in it having significant spatial or temporal variation in systems Wetzel (1975). Chloride originates from the weathering and leaching of calcareous deposits as well as atmospheric precipitation. In the AOSERP study area, large winter chloride maximums were detected for the Steepbank, Hangingstone and MacKay Rivers thereby indicating potential influences attributed to ground water inputs rather than weathering of local calcareous deposits. Although chloride increased during the winter in the Muskeg River, summer concentrations were greater than winter ones, indicating the effects of weathering and leaching of local calcareous deposits in this basin. All potential sources of chloride had little influence on the Ells River as chloride was undetectable. Since a great range of mean values ie. 0 to 11.5 mg L^{-1} were found for this area it would appear that an additional factor influences lotic chloride concentration. Smith (1979) indicated that marine rock formations occur widely and contribute chloride via groundwater, the effect of which is most pronounced during the winter. Values however remain close to those reported by Wetzel (1975) ie 8.3 mg L^{-1} for fresh water systems.

5.2.1.12 Nitrate Nitrogen

One of the most common sources of nitrogen used for growth by algae is nitrate (Stewart, 1974). The sources of nitrate-nitrogen to aquatic systems include precipitation, nitrogen fixation and runoff. Nitrate nitrogen is readily leached from soils (Whitton, 1975) hence at the source of the Ells River (the Birch Mountains) limited precipitation on the eastern slopes may account for the lack of distinct seasonal patterns (Neil and Evans, 1979). In the remaining rivers distinct fall peaks were evident coincidentally with the period of increased rain and runoff as well as leaf drop throughout the basins. In the Muskeg River nitrate-nitrogen fluctuated most dramatically during the 1978 fall spate. Moreover nitrate-nitrogen was significantly correlated with discharge in the Steepbank River, and in a positive manner. Similar trends were also evident in the Muskeg, Hangingstone and MacKay rivers but only at the p 0.25 level. Such trends provide further evidence that the major nitrogen source stems from allochthonous material reaching the rivers in surface runoff. Further sources of nitrogen originate within the rivers themselves from the nitrogen-fixing blue-green algae and associated bacteria. The former represent the major algal group of these rivers.

5.2.1.13 Phosphate-phosphorus

The five northeastern Alberta Rivers discussed herein represent lotic systems unaffected by phosphorus additions originating from human activity. The rivers do however originate in areas rich in organic matter and can therefore be expected to exhibit higher than average total phosphorus concentrations (Wetzel, 1975). The range of values for most uncontaminated surface waters is between 0.10 and 0.50 mg L^{-1} phosphate phosphorus. This value however is not directly comparable to Wetzels (1975) total phosphorus ranges, as it excludes phosphorus associated with colloidal particulate material removed by filtration.

Akena (1979) reported that total phosphorus ranges from 0.005 mg L^{-1} to 0.56 mg L^{-1} in the Muskeg River. Hence dissolved phosphorus in the Muskeg River (max value 0.352 mg L^{-1} Appendix 10a) represents 63% of the total phosphorus reported by Akena (1979). By addition, our values fall within those reported by Wetzel (1975) for uncontaminated surface waters.

The sources of phosphate phosphorus to lotic systems include decomposition of organic matter, sediment release, runoff and groundwater inputs. These factors with the exception of surface runoff contributed significantly to winter maximum concentrations among all rivers. Low summer values are related to adsorption of phosphate ions on sediments (Akena, 1979) and biological uptake by algae as well as other aquatic vegetation. Values were particularly high in the Hangingstone River (ie 0.60 mg L^{-1}) during the winter period and as low as the Muskeg River during the summer period (0.006 mg L^{-1}). This finding may suggest a human influence in the Hangingstone River basin over the winter period, an impact possibly related to the town of Fort McMurray. In the Muskeg and Steepbank Rivers phosphate-phosphorus was negatively related to discharge ($r = -0.295$, $p < 0.05$; $r = -0.625$, $p < .005$ respectively). Similar effects of dilution on phosphate-phosphorus by increased water discharge have also been reported by Wang and Evans (1970) for the Illinois River, USA and Charlton _et al_ (1985) for the Bow River located in Southern Alberta.

5.2.1.14 Dissolved Silica

Dissolved silica, the major element essential for the formation of diatom frustules, originates from the degradation of alumino-silicate minerals. The amount of silica in solution is chemically modified by surface adsorption (on inorganic particulates) of silicic acid which reduces solubility (Akena, 1979), algal uptake and dilution from spring runoff. Dissolved silica and discharge were negatively correlated (p .005) in all but the MacKay and Ells Rivers (Appendix 10), hence disputing Akena (1979) where he indicated that silica is only slightly affected by streamflow and primarily affected by algal uptake in the spring. Winter high values are primarily derived from shallow groundwater entering streamflow during leaseflow periods.

5.2.1.15 pH and Total Alkalinity

All of the rivers considered during the study were yellowish brown to dark brown in color. Except for the Ells the uppermost regions which meander through muskeg were darker in color. Despite the acid nature of their origins, the water at the routine sampling sites was basic due to the presence of limestone substratum and local geology. The pH which ranged from winter lows of 6.0 in the Ells also increased to 9.0 during the summer months. Similar seasonal patterns were detected in the other rivers. Total alkalinity on the other hand peaked during the winter months when biological activity was reduced and decreased during the spring and fall seasons as biological activity accelerated. pH and total alkalinity therefore mirror each other, i.e., the primary producers reduce ambient free CO_2 and calcium bicarbonate (through the precipitation of $CaCO_3$) while increasing the pH. Moreover the continual addition of free carbon dioxide from the atmosphere allows aquatic mosses (Fontinalis) and the red alga Batrachospermum to survive. Ruttner, (1960) indicated that these species specifically require free CO_2 in order to photosynthesize.

5.2.2 Temporal Epilithic Algal Changes

5.2.2.1 Species Composition and Cell Numbers

5.2.2.1.1 Species Composition

Numerically, Cyanophycean algae were the most important epilithic algae. *Lyngbya aerugineo-caerula*, *Phormidium* sp., *Calothrix braunii* and *Anabaena affinis* and *Nostoc* spp., frequently dominated. The epilithic communities were often several millimeters thick. Diatoms followed the blue-greens namely, *Synedra ulna*, *Synedra rumpens*, *Gomphonema olinaceum*, *G. acuminatum*, *G. longiceps* v. *subclavata*, *Nitzschia fonticola*, *N. palea*, *Achnanthes lanceolata*, *Epithemia sorex*, *E. turgida*, *Cocconeis placentula* and *C. pediculus*. Fjerdingstad (1950) found that *Phormidium* spp. and *Nitzschia palea* are particularly tolerant of organic enrichment. Marker, (1976a) noted that *Phormidium* grew best in the shade of riparian vegetation, and deep pools where the substrata was relatively stable. Hence it would appear that *Phormidium* is particularly well adapted to development in these rivers which are not only rich in organic matter but also have reduced light penetration due to their yellowish-brown to dark brown color. Schoeman (1973) noted that *Nitzschia palea* and *Nitzschia fonticola* both inhabit oxygen-rich, alkaline freshwaters and are good indicators of eutrophic conditions. Both *Synedra ulna* and *S. rumpens* favour weakly alkaline water and *S. ulna* as well as *Achnantes lanceolata* and *Cocconeis pediculus* are particularly intolerant of strong oxygen deficiencies (Schoeman, 1973). The remaining diatom species range from pH-indifferent to weakly alkaline, indicators.

In the Hangingstone River Chlorophycean algae rather than diatoms were the second most abundant. *Stigeoclonium pachydermum* and

Cladophora glomerata were dominant. These species are morphologically similar i.e. branched, firmly attached thalli (Prescott, 1961), which were tolerant of the rapid abrasive nature of the Hangingstone River. Rhodophycean algae were found throughout all rivers except at the Ells. Batrachospermum vagum found in the Muskeg and Steepbank Rivers has been shown to prefer shaded cool (less than 20°C) flowing waters (Parker et al, 1973). Since this species was also found at unshaded sites it would appear that the characteristically brown water again favours the development of epilithic communities adapted to lower light intensities. Dillard (1966) found that both the red alga Batrachospermum and Audouinella require low light. The critical factor however which influenced either genus was temperature. Light and temperature also play critical roles with respect to diatom populations however it is difficult to separate these variables due to their interrelations in photosynthesis (Whitton, 1975).

5.2.2.1.2 Cell Numbers

Moore (1974), after examining nine rivers of southern Baffin Island found that benthic algal numbers exhibit a bimodal peak, one in June-July the other in September. A similar pattern was found for the rivers investigated during this project. Cell numbers however found for north eastern Alberta Rivers were higher than those reported by Moore (1974). Mean cell numbers ranged from 2.36 10^{10} m^{-2} in the Steepbank to 63.80 10^{10} m^{-2} in the Ells. Spectacular development of diatom populations were observed during the fall season in most rivers and during the summer as well in the Muskeg and Ells Rivers. Marker (1976a) similarly reported summer peaks in Bere Stream, England. During the summer months however, it appeared that diatoms were more abundant in the swiftly flowing shallow river regions. Marker (1976a) attributed this pattern to diffusion of gases, nutrients and light attenuation. Reisen and Spencer (1970), ascribed the seasonal patterns to high flow. McIntire (1968) showed that biomass increased in artificial streams as a result of increasing irradiance and current velocity. Gruendling (1971) found that a myriad of factors, chemical and physical, as well as biotic cause cell numbers to fluctuate. Among the five rivers no one over-riding nutrient or physical factor was responsible for controlling fluctuations and population sizes of the major algal groups. Dissolved silica appeared to be potentially limiting to diatom growth in two rivers, the Hangingstone (e.g., entire study period $r = 0.359$, $p<0.10$; open water period 1978 $r = -0.614$, $p <0.10$) and the MacKay (e.g., open water period 1978 $r = -0.558$, $p< 0.10$) rivers. Therefore, even this relationship was inconsistent from year to year in these two rivers. Wang and Evans (1969), and Edwards (1974) also found similar relationships in their studies, whereas Marker (1976) did not in shallow chalk streams in southern England. No other nutrient correlated with diatom growth in any river investigated here. Irradiance was correlated with diatom growth in the MacKay and Ells rivers (e.g., MacKay River (a) entire study period $r = -0.305$, $p< 0.25$; open water period 1978 $r = -0.558$, $p < 0.10$ and Ells River (a) open water period 1978 $r = -0.472$, $p< 0.10$, (b) open water period 1978 $r = -0.870$, $p<0.05$). Temperature was also correlated with diatom growth in the Ells River (open water period 1978 $r = -0.836$, $p< 0.05$). Current velocity was correlated with diatom growth in only the Muskeg (open water period 1978 $r = 0.256$, $p< 0.25$), MacKay (open water period 1978 $r = -0.645$, $p<0.10$) and Ells (a) open water period 1978 $r = 0.626$, $p< 0.25$, (b) open water period 1979 $r = -0.417$, $p < 0.25$) rivers and discharge only in the latter two rivers (e.g., MacKay River open water period 1978 $r = 0.739$, $p < 0.05$, and Ells River (a) open water period 1978 $r = 0.599$, $p < 0.25$ and (b) open water period 1979 $r = -0.472$, $p < 0.25$). Therefore, physical factors appeared more important than nutrients, a phenomenon not uncommon with diatoms in flowing systems (c.f. Moore 1977).

Nutrient correlations were less clear with the Chlorophyta. Calcium was implicated in the Muskeg River (open water period 1978 $r = -0.523$, $p < 0.10$), silica in the Steepbank River (entire study period 1979 $r = -0.264$, $p < 0.25$, open water period 1978 $r = -0.753$, $p < 0.05$; open water period 1979 $r = 0.541$, $p < 0.25$) and iron in the MacKay River (open water period 1978 $r = -0.609$, $p < 0.10$); none was limiting in either the Hangingstone or Ells rivers. Neither irradiance nor temperature was correlated with Chlorophycean growth or demise. However, current velocity and discharge were negatively correlated with Chlorophycean growth in the Steepbank river (open water period 1978-discharge $r = -0.664$, $p < 0.10$, current velocity $r = -0.786$, $p < 0.05$), Hangingstone (open water period 1978-discharge $r = -0.452$, $p < 0.25$, current velocity $r = -0.454$, $p < 0.25$; open water period 1979-discharge $r = -0.976$, $p < 0.005$, current velocity $r - 0.938$, $p < 0.005$), MacKay (entire study period-discharge $r = -0.259$, $p < 0.10$, current velocity $r = -0.466$, $p < 0.05$; open water period 1978-discharge $r = -0.557$, $p < 0.10$, current velocity $r = -0.722$, $p < 0.05$; open water period 1979-discharge $r = -0.440$, $p < 0.25$, current velocity $r = -0.764$, $p < 0.05$) and Ells (open water period 1978-discharge $r = -0.521$, $p < 0.25$, current velocity $r = -0.514$, $p < 0.25$) rivers. Thus in spite of the variability, physically disruptive forces were most important in potentially affecting

Chlorophycean algal populations particularly during the open water period of 1978.

Only nitrate-nitrogen correlated with the Cyanophyta and that was in the Hangingstone River (entire study period $r = -0.222$, $p < 0.25$; open water period 1978 $r = -0.581$, $p < 0.10$). Of the physical factors only current velocity and discharge were important particularly in the Hangingstone (entire study period-discharge $r = -0.325$, $p < 0.25$, current velocity $r = -0.301$, $p < 0.25$; open water period 1978-discharge $r = -0.627$, $p < 0.10$, current velocity $r = -0.639$, $p < 0.10$; open water period 1979-discharge $r = -0.696$, $p < 0.10$, current velocity $r = -0.647$, $p < 0.10$) and MacKay (open water period 1978-discharge $r = -0.371$, $p < 0.25$, current velocity-no significant relationship). Again physical forces appeared most important. Members of the Rhodophyta correlated with irradiance in the Muskeg (open water period 1978 - $r = -0.421$, $p < 0.10$) and Steepbank (entire study period $r = 0.412$, $p < 0.05$; open water period 1979 - $r = 0.494$, $p < 0.25$) rivers as well as a number of other parameters in the Steepbank River (e.g., nitrate-nitrogen, current velocity and discharge).

5.2.3 Temporal Standing Crop Changes

5.2.3.1 Epilithon

Chlorophyll a, the primary photosynthetic pigment in all oxygen evolving photosynthetic organisms has been used extensively as a measure of algal standing crop. (Marker and Gunn (1977), Waters (1961), Moss (1976b), Round (1981)).

Marker and Gunn (1977) found that due to the presence of various intermediate degradation products chlorophyll a does not necessarily correspond to live-cell counts. A similar lack of continuity was noted during this study. Standing crop estimates were highest during the fall season of 1978 in all rivers except the Muskeg and Ells which had higher standing crop estimates during 1979. Interestingly peak standing crops occurred earlier in the fall of both years at the Ells River site.

Mean epilithic chlorophyll a values for the five rivers (Table 30) ranged from 7.94 to 43.2 mg chlorophyll _a_ m^{-2}. The Ells river which supported the highest mean chlorophyll _a_ is similar to the calcareous lowland streams of England during the summer (40 - 100 mg m^{-2}) (Marker, 1976a). Peak fall values in Northeastern Alberta are similar to spring peak chlorophyll _a_ values reported by Marker (1976a) i.e. 200 - 300 mg chlorophyll _a_ m^{-1}. The range of values reported for other epilithic communities i.e. hot springs and calcareous mountain rivers however exceed standing crop estimates for the rivers investigated during this study (Round, 1981). Due to the extreme variability among lotic systems not only temporally but also annually, it would appear that changes in chlorophyll _a_ are connected to the changes in population structure. Specific dominance by diatoms i.e. spring or fall may yield particularly large standing crop estimates using chlorophyll _a_ as an indicator. The presence of large numbers of blue green algae on the other hand may yield an underestimate of chlorophyll _a_ due to assessory pigments which remain undetected when only chlorophyll _a_ corrected for phaeophytin is used to measure epilithic algal standing crop.

Correlations between standing crop and various other physical and chemical factors over the entire study period and the open water periods of 1978 and 1979 were examined to provide possible information about any potential controlling factors. The results are present in Appendix 11. Over the entire study period, no one nutrient was limiting to standing crop size. This was undoubtedly due to physical limitations during the winter months coupled with nutrient increases under ice-cover through decreased flow. No nutrient correlated in the Muskeg and MacKay Rivers (Appendix 11) while those that did in the Steepbank River were positively correlated. Only in the Ells River did significant negative correlations occur (e.g. with SiO_2 and PO_4^{-1}). Thus, in general nutrient levels are more than adequate to support algal populations. Of the physical factors, current velocity and discharge were consistently the most important except in the Ells where irradiance was the major limiting factor. Thus, physically disruptive forces appear to be more important during the entire study period than nutrient levels in all but the Ells River.

Physical factors in particular can change substantially and rapidly, sweeping away not only the algae but also the rocks to which they attach. Moreover, accumulation of epilithon increases resistance to flow particularly if the organic matrix becomes impregnated with sediment and detritus. Both Hynes (1970) and Whitton (1975) emphasized the effects of current. McIntire (1966) demonstrated its devastating impact in laboratory streams. Blum (1963) concluded that it is a primary factor which governs not only organic accumulation but also the distribution of species.

5.2.3.2 Phytoplankton

The temporal patterns of northern lotic phytoplankton wax and wane have been related to factors such as temperature and nutrient availability (Moore 1979). Egborge (1973, 1974) indicated that Oshun River phytoplankton were predominantly benthic detached and epilithic species. Whitton (1975) however stated that true phytoplankton populations develop in large slow flowing rivers, and Hynes (1970) noted that backwater phytoplanktonic communities develop in lotic systems.

Although planktonic chlorophyll a appeared to be related to benthic chlorophyll a the correlation was not statistically significant for $p = <0.05$. Planktonic chlorophyll a fluctuated widely and highest values often coincided with or followed periods of high benthic chlorophyll a. Diatoms were the dominant algal division found in the plankton, mainly senescent epilithic species. Hooper (1947) similarly reported that diatoms were more abundant in the plankton of five rivers located in the Yukon and Mackenzie River systems and he related their origin to local lakes and ponds. Antoine (1983) reported finding direct correlations between water temperature and transparency with the phytoplankton whereas water level and currents manifested inverse correlations for the Tigris River, Iraq. Unfortunately however he disregarded the epilithic community which may in fact be similarly responding to physical factors. Moreover most of the species which he identified were also detected in the epilithic communities of Northeastern Alberta Rivers.

5.2.4 Temporal Productivity Changes

5.2.4.1 Epilithon

The difficulties associated with the highly dynamic and heterogenous nature of lotic systems has given rise to several incomparable alternative approaches to assaying primary production (Odum 1956, Wright and Milles 1967, Duffer and Dorris 1966). Their methods ranged from measurement of diurnal dissolved oxygen most commonly to the use of pH and carbon dioxide fluctuations. Whitton (1975) however pointed out that only approximate estimates of gross photosynthesis could be gained through these methods.

Although the closed circulating chambers developed during this study were smaller and less regulated with respect to internal circulation of water than those employed by Marker (1976c) they were dependable and portable. Moreover, the use of the same technique yielded comparisons among five rivers.

The temporal variation of primary productivity fluctuated more than standing crop estimates. Both standing crop and primary production were on average highest in the Ells River followed by the Muskeg River and Steepbank respectively. The Steepbank and Hangingstone supported closely similar epilithic standing crops and were similarly productive. The MacKay River which had a particularly diverse eplithon had the lowest standing crop and production. The same assay techniques were applied to larger rivers located in Southern Alberta (Charlton, Hamilton, Cross, unpublished). They reported much higher mean standing crop values as well as higher rates of ^{14}C uptake. Southern Alberta Rivers

however in addition to having a more temperate climate are dramatically influenced by man-induced eutrophication. The Bow River for example during a two year period averaged 141 mg chlorophyll a m^{-2} and 77 mg C m^{-2} hr^{-1} (Charlton, Cross, Hamilton unpublished). Northeastern Alberta Rivers averaged 25 mg Chlorophyll a m^{-2}, and 17 mg C m^{2} hr^{-1}.

Epilithic algal standing crops were correlated with primary productivity in all but the MacKay River during the open water period of 1979 (Appendix 8). The factors which controlled epilithic primary productivity were more variable. Actually, no factor examined correlated with epilithic primary productivity during the open water period of 1978 other than standing crops in the Muskeg, MacKay and Hangingstone Rivers. In the Ells and MacKay Rivers however many factors correlated with productivity. A summary of these factors is given in Appendix 8.

The mean specific rates of photosynthesis were also compared among the five rivers. The highest rate was calculated for the Muskeg River (8.64 mg C (mg Chlorophyll a)$^{-1}$.hr^{-1}) followed by the Ells (3.6 mg C (mg Chlorophyll a)$^{-1}$.hr^{-1}), the Steepbank (3.01 mg C (mg Chlorophyll a)$^{-1}$.hr^{-1}), MacKay (1.16 mg C (mg chlorophyll a)$^{-1}$.hr^{-1}) and the Hangingstone (0.82 mg C (mg Chlorophyll a)$^{-1}$.hr^{-1}). These values are greater than found by McConnell and Sigler (1959), Bowbowna (1972), and Marker (1976b) for benthic algae in rivers. The mean value in the MacKay River was similar to that reported by Hickman (1971a) for epiphytic algae in a small pond. Values for the other rivers were similar to values found by Hickman and Klarer (1975) for epiphytes in Lake Wabamum, Alberta (range 5.3 to 20.8 mg C (mg chlorophyll a)$^{-1}$.h^{-1}).

5.2.4.2 Phytoplankton

Although phytoplankton standing crops were on average higher in the Hangingstone River the highest mean rate of ^{14}C uptake was found in the Ells River. Higher production values could be expected in the Ells due to the sampling sites proximity to a series of lakes which give rise to the Ells. Similar values found in the Muskeg probably reflect the presence of actively growing cells originating from the upstream pools and backwaters. Values found for these rivers exceed those found for southern Alberta Rivers (Charlton *et al* 1985) possibly due to the slow flowing nature at their origin as well as frequent backwaters arising from pools formed by beaver dams and organic obstruction of the flow.

5.2.4.3 Microhabitat Differences

Lotic primary productivity has been shown to vary not only seasonally but spatially. Differences in microcolonization patterns particularly in relation to current velocity have been reported by Round (1981) Gessner (1955) and Gumtow (1955), Korte and Blinn (1983). Patrick (1970) described a stream ecosystem as consisting of many small, compact communities, in which the algae vary in habitat and distribution. Gumtow (1955) showed that even within local habitats, micro-distributional variations are evident. Microhabitat differences have been attributed to a variety of factors including current velocity (Jones 1978, Gumtow 1955), grazing (Hynes, 1970), detrital microcosms (McIntire and Phinney, 1965), light or lack thereof (shading) (Whitton, 1975), (Hynes, 1970), and the availability of substrate suitable for colonization (Round, 1981). None of these studies however has employed the light/dark bottle technique to assay epilithic primary production in various microhabitats simultaneously.

When shore (15 cm depth) midstream (50-60 cm depth) and shaded midstream epilithic productivity were compared, shading reduced the mean rate of production as well as the photosynthetic index or efficiency. Interestingly however the quantity of chlorophyll _a_ increased. This finding suggests a chromatic adaptation _i.e._ the blue green dominant epilithic algae may increase their chlorophyll _a_ content. Evidence currently exists for this phenomenon among marine algae (Round, 1981), hence we could expect freshwater species particularly those adapted to survival in streams containing colored water (which changes seasonally) to maximize their utilization of incoming light. Towns (1981) shaded a lotic system sufficiently to allow only 6% of the outside light beneath a canopy. He found that this degree of shading resulted in the disappearance of periphyton. This conclusion, however, specifically demands careful examination of the substrata to ensure that species not visible to the naked eye are not present.

The microhabitat study provided evidence that epilithic algal standing crops develop earlier and achieve higher values initially in the shallow river regions and although chlorophyll a never reaches the levels of those found for midstream sites, the epilithon are very productive. Midstream communities which receive less light due to absorbance and reflection from the overlying water, on the other hand, have a lower photosynthetic index. Shaded habitats respond less rapidly but their efficiency closely resembles that found in the shore region. Thus it would appear that the epilithon of the brown water alkaline streams of northeastern Alberta are particularly well adapted to variable incoming light. The heterogeneity of lotic epilithic communities therefore demands particular caution with respect to defining epilithic standing crops and productivity. All microhabitats must be examined during any attempt to discern quantitatively lotic epilithic algal standing crops and productivity.

5.2.4.4 Substrata Comparison

Evidence currently exists to suggest that size, texture and chemistry may all, at times, influence the distribution of benthic algae in streams (Whitton, 1975). Nielsen (et al, 1984) found that rock substrate showed higher absolute values of chlorophyll a (56%) than those collected from glass substrates. Wetzel (1975) believed that the number of discrepancies found between algal populations on natural and artificial substrates were sufficiently large to necessitate a thorough evaluation for each study.

Although artificial substrata were not employed to routinely monitor epilithic primary production, visual observations did suggest that discrepancies existed between naturally occurring bitumen and rock substrata. Moreover synthetic crude oil derived from bitumen was shown to have a stimulatory action upon bacterial, algal and macroinvertebrate organisms in the Muskeg River (Lock et al, 1981a, 1981b).

In the Steepbank River, microalgae were more abundant upon rock (limestone) substrate while macroalgae, particularly *Nostoc commune*, was more abundant upon bitumen substrate. However, epilithic primary productivity was 22% higher on the rock substrata than on the bitumen substrata. Hellebust *et al* (1975) found that crude oil exposed to benthic algae initially caused bleaching of blue-green algae at super-optimal light intensities, however in long term experiments it was stimulatory to some blue green algae. In the Steepbank River the potential for bleaching is reduced by the brown coloration of the overlying water, moreover the benthic communities are continually exposed to weathered oils derived from local runoff as well as bituminous substrate erosion. Thus it would appear that rock substrata are better suited to epilithic community development, Bitumen substrata do however provide a selective advantage for the development of species such as *Nostoc* spp. where the individual filaments are protected from high concentrations of newly released oil products. During periods of high water temperatures, bitumen substrata were in fact found to be very soft, weak and brittle and continually contaminated equipment with tar. The soft easily eroded nature of the bitumen substrate may also be less suitable for colonization by micro-blue-green algae filaments. Conversely *Nostoc commune* may utilize the bitumen substrate as a source of nutrients and hence outcompete other epilithic species. Further investigation is required to discern the specific reasons for higher numbers of _Nostoc commune_ on bitumen substrate; it may in fact be simply related to bitumen providing a substrate more suitable for colonization by _Nostoc commune_ reproductive structures.

5.2.4.5 Diurnal Experiment

There is an obvious variation in photosynthetic activity between day and night, but less obvious is a disparity in the amount of carbon fixed during succeeding intervals in the light period (Round, 1981). Generally 2-4 hr experiments are performed _in situ_ to discern phytoplankton carbon uptake and the data extrapolated to the whole light period. Round (1981) indicated that such extrapolation often yields misleading values hence daily rates should be computed only from a sequential series of short exposures.

Routine studies to estimate epilithic primary productivity were conducted from 1000 through 1400 hrs. Values averaged 26.2 mg C m^{-2} hr^{-1} for this period during the diurnal experiment. The average rate for the entire 24 hour period was 13.9 mg C m^{-2} hr^{-1}. The average rate however for the daylight period (0800-2000 hrs) was 27.4 mg C m^{-2} hr^{-1}. Thus the routine experiments conducted from 1000 hrs through 1400 hrs closely estimated mean epilithic primary productivity for the daylight period (0800-2000 hrs).

Each successive series of overlapping incubations utilized whole rock samples totalling 106 individual estimates of epilithic algal standing crop. Mean standing crop estimates per incubation set ranged from 5.4 mg chlorophyll _a_ m^{-2} to 13.9 mg chlorophyll _a_ m^{-2}. The grand mean standing crop estimate was 7.1 mg chlorophyll _a_ m^{-2} having a standard deviation of 5.13. Hence lotic epilithic algal standing crops are extremely heterogeneous.

The high degree of variability among samples can be attributed to not only physical and chemical regimes but also the species composition and physiological state of the epilithon. Evidence currently exists to indicate that chlorophyll a content of cells also exhibits a circadian rhythm (Round, 1981). The high degree of heterogeneity among epilithon, however render it virtually impossible to define whether or not this factor contributed to the heterogeneity observed during the diurnal study.

In general the Muskeg River exhibits a peak of carbon fixation as well as photosynthetic efficiency which occurs between mid-morning and the early afternoon. Measurement of carbon uptake during this period provided a representative measure of epilithic primary production. Caution however is warranted with respect to defining epilithic algal standing crops especially if small sample techniques are employed.

5.2.5 Temporal Nitrogen Fixation Changes

5.2.5.1 Epilithon

Seasonal studies of epilithic algal nitrogen fixation in five brown water rivers revealed distinct peaks of fixation during the summer as well as much smaller rates when the water temperature fell below 5°C and under ice-cover of winter. However, nitrogen fixation was detectable over the entire temperature range encountered in these rivers (Fogg and Stewart 1968, Horne 1972, Stewart 1970). Cyanophycean algae were numerically dominant throughout the year (Hickman et al 1978, 1980) with greatest development during the summer, thus nitrogen fixation paralleled their wax and wane in their biomass. Moreover, a direct correlation existed between mean Cyanophycean population size for each river and both light and dark incubation. Light fixation rates were greater than those in dark confirming the light dependent nature of nitrogen fixation (Dugdale and Dugdale, 1962, Goering and Ness 1964, Horn and Fogg 1970). The high dark fixation rates found during the study were probably due to epilithic community exposure to light prior to the experiement which began at 1000 hours (Dugdale and Dugdale, 1962, and Fay, 1976).

Light nitrogen fixation among the five rivers ranged from 1.52 to 27.14 u moles N_2 hr^{-1} m^{-2}. These values are similar to those found by Horne and Carmiggelt (1975) and Horne (1975) for Californian streams. Both the Californian streams and the rivers (except the Muskeg) of northeastern Alberta supported extensive development of heterocystous Nostoc spp which formed variously sized gelatinous clumps on the stable rock substrata. In the Muskeg River both heterocystous and non-heterocystous blue-green algae which dominated the epilithon, fixed less nitrogen than in the other rivers. This routine study site however was exceptional. Only very large stable boulders supported Nostoc and samples could not be obtained for assay which included Nostoc spp.

Horn and Fogg (1970) found that rates of nitrogen fixation in aquatic systems are highest when nitrate concentrations are less than 0.3 mg L^{-1}. With the exception of the MacKay River nitrate-nitrogen concentrations averaged less than this value in all rivers. Hence blue-green algae as well as other nitrogen-fixing components of the epilithic community are probably important contributors to the overall nitrate-nitrogen budgets of these northeastern Alberta rivers.

5.2.5.2 Microhabitat Differences

As indicated earlier, blue-green algal species were dominant among all of the microhabitats investigated in the Muskeg River. Both heterocystous and non-heterocystous species were present however colonial species were dominant in the shaded midstream while filamentous species were dominant in the unshaded areas. Pronounced fluctuations of numbers were detected during the summer in the unshaded habitats however, only a fall peak was detected in the shaded habitat.

Artificial shading depressed the rate of nitrogen fixation as well as the amplitude of nitrogen fixation rates. Potts and Whitton (1977) also noted the marked influence of light on nitrogen fixation and reported that both heterocystous and non-heterocystous blue-green algae are capable of fixing elemental nitrogen. Rudd and Hamilton (1975) emphasized the need to include assays of low light regions when estimating aquatic nitrogen fixation.

This study provides further evidence of the impact of not only shading but also the need to assay both light and dark samples when defining lotic nitrogen fixation. Moreover the rates of nitrogen fixation varied spatially and were greatest in the midstream epilithic community. The marked spatial variability of nitrogen fixation therefore demands careful assessment of lotic characteristics prior to estimating daily or annual nitrogen inputs from biological sources.

The midstream unshaded community of the Muskeg river represents the lotic habitat which is the most metabolically active. Both heterotrophic and autorophic organisms operate simultaneously to maintain community stability.

5.2.5.3 Substrata Comparison

Blinn (*et al*, 1980) suggested that microtopographic differences among lotic substrates and possibly the rate of substrate solubilization may affect colonization. A definitive example of the chemical interaction between substratum and colonizers was presented by Parker (*et al* 1973). They found that particular elements and substrate types were species-specific. In the Steepbank River *Nostoc commune*, a known nitrogen fixer, (Stewart, 1974) was particularly abundant on bitumen substrata. Horne (1975) and Horne and Carmiggelt (1975) showed that *Nostoc* species grows on stones mainly in early summer and fixes nitrogen at a maximum rate during the day, is lowest in the evening but picks up during the night.

In the Steepbank River total blue green algal numbers were higher on rock substrates but nitrogen fixation was highest on the bitumen substrate where *Nostoc commune* was most abundant. Both light and dark assays indicated the significant contribution of *Nostoc* colonies toward the total rate of nitrogen fixation. During early September however nitrogen fixation and *Nostoc* colonies suddenly decreased exhibiting a temporal pattern similar to that reported by Horne and Carmiggelt (1975). They attributed this phenomenon to scour resulting from turbulent water flow which prevented autumn establishment of *Nostoc* colonies. This phenomenon also occurred in the Steepbank River. Therefore physical forces also exert an influence on potential lotic nitrogen fixation, the effect of which is more profound for bitumen substrata than rock substrata.

5.2.5.4 Diurnal Experiment

The diurnal variation of nitrogen fixation and the effects of light upon this process are indeed complex but related. Although it is a light dependent process (Stewart, 1974); some authors have also shown that blue-green algae continue to fix nitrogen during the dark period (Hay, 1965 , Horne and Fogg, 1970 , Duong 1972). The highest rate of nitrogen fixation (3.15 u moles N_2 m^{-2} hr^{-1}) was detected during the morning (after 0800 hrs). Horne (1979) similarly reported this phenomenon for Clear Lake, California and in both cases the rates decreased after the morning peak despite increasing irradiance. Nitrogen fixation efficiency (u moles N_2 mg^{-1} chlorophyll $\underline{a}$ m^{-2} hr^{-1}) in clear glass bottles was maximum between 1800 and 2300 hr, whereas dark bottle efficiency was highest between 2300 and 0400 hr; thus it would appear that recent light exposure is critical for the production of enzymes and other products required for the process of nitrogen fixation after which the efficiency of nitrogen fixation is at a maximum. It would seem however that epilithon has a limited capacity to continue this process as nitrogen fixation rates declined to a minimum by early morning just prior to daybreak (0400 hrs). The occurrence of continual dark fixation during both the light and the dark period incubations suggests that nitrogen fixation is a characteristic activity associated with facultative heterotrophes which operate whether or not light is available. The specific contribution by algae apart from the role of bacterial nitrogen fixers however were not defined during this study. Teal and Berlo (1970) reported that bacterial nitrogen fixation in salt marsh sediment was more than ten times larger than algal fixation. Therefore further investigation is essential for a better understanding of the role of eplithic algae in relation to lotic nitrogen fixation.

5.2.6 Cluster and Principal Components Analysis

Although cluster analysis had several important disadvantages it proved to be a useful tool for evaluating such a large data base. Cluster analysis produced hierarchic clusters regardless of the structure of the original matrix. Hence data which may have been uniformly distributed in ecological hyperspace were clustered into a hierarchy even if no such structure existed in nature. This technique also gives equal weight to each variable included in the study. Despite these assumptions some relationships were discerned. It showed that the lotic systems located in northeastern Alberta are primarily affected by fluctuations in river discharge, velocity, temperature and nutrients which profoundly influence the epilithic communities. Annual spates explain 22.93% of the data variance and season-related patterns of discharge, velocity and nitrate-nitrogen (lotic influence) act as major factors explaining an additional 16.58% of the data variability. 12.39% of the data variance remaining is primarily explained by the influence of nutrients specifically nitrate-nitrogen and phosphorus. Temperature is also important particularly in relation to diatom and Chlorophycean eplithic algae. Other authors have underlined the importance of the hydrologic regime for large tropical rivers (Sioli, 1975). Garcia de Emiliani and Depetris (1982) and on southern Alberta Rivers (Charlton _et al_ 1985). Due however to a lack of studies quantifying the factors that control the functioning peculiar to these systems, much-needed comparisons are not yet available. Blum (1956) pointed out the frequently abrupt changes which occur monthly as well as weekly in lotic systems. Hence many difficulties surround attempts to correlate biological results with environmental causes.

6. Conclusions

This study has described the major epilithic algal groups, species composition, succession of dominants, standing crops (chlorophyll *a* and cell numbers), primary productivity and nitrogen fixation fluctuations in relation to the physical-chemical regime of five brown water rivers. The factors influencing epilithic algae, their population wax and wane, standing crops, primary productivity and nitrogen fixation have been indicated. No one factor is responsible; rather, interacting factors both disruptive and non-disruptive and of these, current velocity and discharge are most important. The latter is also related to the chemical makeup of the water itself. Thus, discharge and to a lesser extent the biota, modify the nutrient status of the water. Current velocity, a physically disruptive force, is important in affecting and controlling population size, standing crops and primary productivity, the latter through controlling standing crop size. Naturally, some of the epilithic algae grow better in faster flowing water since they are better adapted than others. Their growth is enhanced by increases in current velocity e.g., Cyanophyta compared to filamentous Chlorophyta.

Epilithic algae exhibit an extremely heterogenous spatial variability with respect to standing crop, primary productivity and nitrogen fixation. The midstream epilithic communities are the most stable followed by shore and shaded communities respectively. Even in the presence of 80% shading, eplithic algae are successful suggesting a specific adaptation to low light utilization. In addition, the epilithon of the five brown water rivers exhibited a preference for rock substrata with the exception of *Nostoc commune* which preferred bituminous substrata. There appears to be some relationship between epilithic colonization, and substrate type. Cyanophycean algae are the dominant eplithic forms in northeastern Alberta Rivers followed by diatoms. The epilithon are important sources of new nitrogen to the overall nutrient regimes of the Muskeg, Steepbank, Hangingstone, MacKay and Ells Rivers.

Finally, this thesis has provided an extensive data base which documents the temporal patterns of physical, chemical and biotic variables contributing to the structure and function of lotic systems. It provided evidence of the great dissimilarity which exists between lotic and lentic systems.

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Appendix 1. The algae found at each site in the Muskeg River (= present; - absent).

	Site							
Algae	1	2	3	4	5	6	7	8
CYANOPHYTA								
Anabaena affinis Lemm.	-	+	+	-	-	+	-	-
Calothrix braunii Bornet & Flahault	-	-	-	+	+	+	+	+
Gomphonema lacustris v. compacta Lemm.	-	+	-	-	-	-	-	-
Lyngbnya aerugineo-caerulea (Kutz.) Gomont	+	+	+	+	+	+	+	+
Merismopedia glauca (Ehr.) Naegeli	-	+	-	-	-	-	-	-
Nostoc spp.	-	-	-	-	-	+	+	+
Oscillatoria sp.	-	+	+	+	-	-	-	-
CHLOROPHYTA								
Ankistrodesmus falcatus (Corda) Ralfs.	-	+	-	-	+	+	+	+
Chlamydomonas sp.	+	+	+	-	-	-	-	-
Cladophora glomerata (L.) Kutz.	-	-	-	+	+	+	+	+
Closterium sp.	-	+	-	-	-	-	-	-
Coelastrum scabrum Reinsch	-	+	-	-	-	-	-	-
Crucigenia quadrata Morren	-	-	-	-	-	-	-	+
Scenedesmus bijuga (Turp.) Lager	-	-	-	-	-	-	-	+
Spirogyra sp.	-	+	-	-	-	-	-	-
Stigeoclonium sp.	-	-	-	-	+	-	-	+
CRYPTOPHYTA								
Cryptomonas erosa Ehr.	+	+	-	-	-	-	-	+
C. ovata Ehr.	-	-	+	-	-	-	-	-
Rhodomonas minutum Skuja	-	-	+	-	-	-	-	-

Appendix 1. Continued.

Algae	Site 1	2	3	4	5	6	7	8
PYROPHYTA	-	+	+	-	-	-	-	-
CHRYSOPHYTA								
Chromulina spp.	-	-	+	-	-	-	-	-
EUGLENOPHYTA								
Euglena sp.	-	+	+	-	-	-	-	-
Phacus sp.	-	+	+	-	-	-	-	-
Trachelomonas sp.	-	+	+	-	-	-	-	-
RHODOPHYTA								
Batrachospermum vagum (Roth.) C.A. Agardh.	-	-	-	-	+	+	-	-
BACILLARIOPHYTA								
Achnanthes	+	-	-	+	-	-	-	+
A. lanceolata Breb.								
A. minutissima Kutz.	-	-	-	+	-	-	-	+
Amphipleura pellucida Kutz.	-	-	+	-	-	+	-	+
Cocconeis pediculus Ehr.	+	-	-	-	-	-	-	-
C. placentula Ehr.	-	+	-	+	+	+	+	+
Cyclotella meneghiniana Kutz.	-	-	-	-	-	-	-	+
Cymatopleura solea (Breb.) W. Sm.	-	+	+	-	-	-	-	-
BACILLARIOPHYTA								
Cymbella prostrata (Berk.) Cl.	-	+	-	-	-	-	-	-
C. sinuata Greg.	-	-	-	-	+	-	-	-
C. ventricosa Kutz.	-	+	+	+	+	+	+	-
Epithemia argus Kutz.	+	-	-	-	-	+	-	-
E. sorex Kutz.	+	+	-	-	+	-	+	+

Appendix 1. Continued.

Algae	Site 1	2	3	4	5	6	7	8
Eunotia lunaris (Ehr.) Grun	+	+	+	-	-	-	-	-
Fragilaria capucina Desm.	-	+	-	-	-	+	+	-
F. crotonensis Kitton	-	+	-	-	-	-	-	-
F. pinnata Ehr.	-	+	-	-	-	-	-	-
F. vaucheriae (Kutz.) Peters	-	+	+	+	+	-	-	+
Gomphonema abbreviatum (Agardh.) Kutz.	-	-	-	-	+	-	-	+
G. acuminatum Ehr.	-	+	+	-	-	-	-	-
G. acuminatum v. *coronata* (Ehr.) W. Sm.	+	-	-	-	-	-	-	-
G. lanceolatum Ehr.	+	-	-	-	-	-	-	+
G. olivaceum (Lyngb.) Kutz.	+	+	-	-	+	+	+	-
G. parvulum Kutz.	-	-	-	+	-	-	-	-
Melosira islandica D. Mull.	-	-	+	-	-	-	-	-
Meridion circulare Agardh.	-	-	-	-	-	+	-	-
Navicula cryptocephala Kutz.	+	+	+	+	-	+	-	-
N. cuspidata Kutz.	-	+	+	-	-	-	-	-
BACILLARIOPHYTA								
N. gracilis Ehr.	+	+	+	-	-	-	-	+
N. graciloides A. Mayer	-	+	+	+	-	+	+	-
N. radiosa Kutz.	-	+	+	-	-	-	-	+
Nitzschia acuta Hantzsch.	-	-	-	-	+	-	-	-
N. dissipata (Kutz.) Grun	+	-	-	+	-	-	-	+
N. fonticola Grun.	-	+	-	-	-	-	-	-
N. gracilis Hantzsch.	-	+	-	-	-	-	-	-
N. palea (Kutz.) W. Sm.	+	-	-	+	-	+	+	+
N. recta Hantzsch.	-	+	-	+	-	-	-	-
N. sublinearis Hust.	-	+	-	-	-	-	-	-
Pinnularia gibba Ehr.	-	+	+	-	-	-	-	-
P. molaris Grun.	-	+	+	-	-	-	-	-

Appendix 1. Concluded.

Algae	Site 1	2	3	4	5	6	7	8
Rhoicosphenia curvata (Kutz.) Grun	-	-	-	+	-	-	-	-
Stauroneis phoenicenteron Ehr.	-	-	+	-	-	-	-	-
Surirella angustata Kutz.	-	-	-	-	-	+	-	-
Synedra ulna (Nitzsch.) Ehr.	+	+	+	+	+	+	-	-
Tabellaria fenestrata (Lyngb.) Kutz.	+	+	-	-	-	-	-	-

Appendix 2. The algae found at each site in the Steepbank River (+ present; - absent).

	Site				
Algae	1	2	3	4	5
CYANOPHYTA					
Anabaena affinis	+	-	+	+	-
Calothrix braunii	-	-	+	+	-
Lyngbya aerugineo-caerulea	-	+	+	+	+
Nostoc sp	+	+	+	+	-
Oscillatoria sp	-	+	-	+	-
CHLOROPHYTA					
Ankistorodesmus falcatus	+	-	-	+	+
Chlamydomonas	+	-	+	+	-
Chlorella vulgaris	-	-	+	+	+
Cladophora glomerata	-	+	+	+	-
Cosmarium sp	-	+	-	+	+
Hyalotheca sp	-	-	+	-	-
Microspora Loefgrenii	-	+	+	-	-
Microspora sp	-	-	-	-	+
Pediastrum biradiatum	-	-	-	-	+
PHYRROPHYTA	+	-	-	-	-
CHRYSOPHYTA					
Chromulina sp	+	-	-	-	-
EUGLENOPHYTA					
Euglena sp	+	-	-	-	-
RHODOPHYTA					
Batrachospermum vagum (Roth.) C.A.Agardh	-	+	-	-	-

Appendix 2. Concluded.

Algae	Site				
	1	2	3	4	5
BACILLARIOPHYTA					
Achnanthes sp.	-	-	-	-	+
A. lanceolata Breb.	-	-	+	+	+
A. minutissima Kutz.	-	+	-	-	-
Cocconeis pediculus Ehr.	-	+	+	+	+
C. placentula Ehr.	-	+	+	+	+
Cyclotella meneghiniana Kutz.	-	+	+	+	+
Cymbella cistula (Hemp.) Grun	-	-	-	-	+
C. ventricosa Kutz.	-	-	+	+	+
Diatoma vulgare Bory.	-	+	-	-	+
D. vulgare v. *grandis* (Sm.) Grun	-	+	+	-	-
Epithemia argus Kutz.	-	+	+	-	+
E. sorex Kutz.	-	-	+	+	+
E. turgida Kutz.	-	+	-	-	+
Fragilaria capucina Desm.	-	-	+	+	-
F. pinnata Ehr.	-	-	+	-	-
Fustrulia rhomboides v. *amphileuroides* Grun.	-	-	+	-	-
Gomphonema acuminatum Ehr.	-	+	-	-	-
G. gracile Ehr.	-	+	-	-	-
N. graciloides A. Mayer	-	-	-	+	+
N. radiosa Kutz.	-	-	-	-	+
Nitzschia gracilis Hantzsch.	-	+	-	-	+
N. hantzschiana Rabh.	-	-	+	-	-
N. palea (Kutz.) W. Sm.	-	+	+	-	+
Rhoicosphenia curvata (Kutz.) Grun.	-	-	+	-	-
Rhopalodia gibba (Ehr.) O. Mull.	-	+	+	+	+
Surirella angustata Kutz.	-	-	+	-	-
Synedra ulna (Nitzsch.) Ehr.	-	+	+	+	+
Tabellaria flocculosa (Roth.) Kutz.	+	+	+	+	-

Appendix 3. The algae found at each site in the Hangingstone River (+ present; - absent).

Algae	Site 1	2	3	4	5	6
CYANOPHYTA						
Anabaena affinis Lemm.	+	+	-	+	-	-
Calothrix braunii Bornet & Flahault	-	-	+	-	-	+
Lyngbya aerugineo-caerulea (Kutz.)	+	+	+	+	-	+
Oscillatoria	-	-	+	+	+	-
CHLOROPHYTA						
Chlamydomonas sp.	+	+	-	-	-	-
Chlorella vulgaris Beyer	+	-	+	-	-	-
Closterium sp.	-	-	-	+	+	+
Pediastrum boryanum (Turp.) Meneghini	-	-	-	+	-	-
Pleurotaenium spp.	-	-	-	-	-	-
Spirogyra sp.	-	-	-	-	-	+
CRYPTOPHYTA						
Cryptomonas ovata Ehr.	+	-	-	-	-	-
Rhodomonas minutum Skuja	-	+	-	-	-	-
EUGLENOPHYTA						
Euglena sp.	+	+	-	-	-	-
RHODOPHYTA						
Batrachospermum vagum (Roth.) C.A. Ag.	-	-	-	-	+	+
BACILLARIOPHYTA						
Achnanthes lanceolata Breb.	(a)	+	+	+	+	+
Amphipleura pellucida Kutz.		-	-	-	-	+
Cocconeis pediculus Ehr.		-	-	-	+	-
C. Placentula Ehr.		-	+	-	+	+

Appendix 3. Continued.

Algae	Site 1	2	3	4	5	6
Cyclotella meneghiniana Kutz. (a)	+	+	+	-	-	
Cymatopleura solea (Breb.) W. Sm.	-	-	+	+	-	
Cymbella prostrata (Berk.) Cl.	+	+	+	-		
C. sinuata Greg.	-	-	-	+	-	
C. ventricosa Kutz.	+	+	+	+	-	
Diatoma vulgare Bory	-	-	-	-	+	
Epithemia argus Kutz.	-	-	-	+	-	
E. sorex Kutz.	-	-	+	+	+	
E. turgida Kutz.	-	-	-	+	+	
Fragilaria capucina Desm.	-	+	-	-	+	
F. vaucheriae (Kutz.) Peters	+	+	+	+	+	
Gomphonema abbreviatum (Ag.) Kutz.	+	+	-	-	-	
G. lanceolatum Ehr.	-	-	-	-	+	
G. olivaceum (Lyngb.) Kutz.	-	-	+	-	-	
G. parvulum Kutz.	+	-	-	-	+	
Gyrosigma acuminatum (Kutz.) Rabh.	-	-	+	-	-	
Melosira islandica O. Mull	-	-	+	-	-	
M. varians C.A. Ag.	-	-	+	+	-	
Navicula cryptocephala Kutz.	+	-	-	+	+	
N. graciloides A. Mayer	+	+	+	+	+	
Nitzschia acuta Hantzsch.	-	+	-	-	-	
N. dissipata (Kutz.) Grun.	-	+	-	+	+	
N. palea (Kutz.) W. Sm.	+	+	+	-	-	
N. recta Hantzsch	+	-	-	+	-	
Pinnularia gibba Ehr.	-	-	+	-	-	
Rhopalodia gibba (Ehr.) O. Mull.	-	-	+	+	-	
R. gibberula (Ehr.) O. Mull.	-	-	+	-	+	
Synedra ulna (Nitzsch.) Ehr.	+	+	+	+	+	

(a) Diatom sample lost in transit.

Appendix 4. The algae found at each site in the MacKay River (+ present - absent).

Algae	Site 1	2	3	4	5	6	7	8
CYANOPHYTA								
Anabaena affinis Lemm.	+	+	+	+	-	+	+	+
Chroococcus limneticus Lemm.	-	-	-	-	+	-	-	-
Gomphosphaeria aponina Kutz.	-	-	-	-	+	+	+	-
Lyngbya aerugineo-caerulea (Kutz.) Gomont	+	-	+	+	+	+	+	+
Merismopedia glauca (Ehr.) Naegeli.	-	-	-	+	-	-	-	-
Nostoc spp	-	-	-	+	-	-	-	-
Oscillatoria amphibia C.A. Agardh.	+	-	-	-	-	-	-	-
CHLOROPHYTA								
Ankistrodesmus falcatus (Corda) Ralfs.	-	-	+	+	+	+	+	-
Chlamydomonas globosa Snow	+	+	-	-	-	-	-	-
Chlamydomonas sp.	+	+	+	+	-	+	+	+
Chlorella ellipsoidea Gerneck	+	-	-	-	-	-	-	-
C. vulgaris Beyer	+	+	-	+	+	-	+	+
Claophora glomerata (L.) Kutz.	+	-	+	+	+	+	+	+
Closterium sp.	-	-	+	+	+	+	+	-
Coelastrum scabrum Reinsch.	-	-	-	+	-	-	-	-
Cosmarium spp.	-	-	+	+	+	+	+	-
Gloeocystis gigas (Kutz.) Lager	-	-	-	+	+	-	-	-
Microspora Loefgrenii (Norst.) Lager	-	-	+	-	-	-	-	-
Oedogonium sp.	-	-	+	+	+	-	+	-
Pediastrum biradiatum v. *emarginatum* *F. convexum* Prescott.	-	-	-	-	+	-	-	+
Scenedesmus acutiformis Schroeder	-	-	-	-	+	+	+	+
S. bijuga (Turp.) Lager.	-	-	+	-	+	+	+	+
S. quadricauda (Turp.) de Breb.	-	-	-	-	+	-	-	+

Appendix 4. Continued.

	Site							
Algae	1	2	3	4	5	6	7	8
Spaerocystis schroeteri Chodat	-	-	-	-	-	+	-	-
Sphaeroplea annulina (Roth.) C.A. Agardh.	-	-	-	-	+	-	-	-
Stigeoclonium sp.	-	-	+	-	+	+	+	-
Ulothrix sp.	-	-	-	-	+	-	-	-
CRYPTOPHYTA								
Cryptomonas ovata Ehr.	-	+	+	-	-	-	-	-
Rhodomonas minutum Skuja	+	+	-	-	-	-	-	-
PYRROPHYTA	+	-	-	-	-	-	-	-
CHRYSOPHYTA								
Chromulina spp.	-	-	-	+	-	-	-	-
Dinobryon sertularia Ehr.	+	-	-	-	-	-	-	-
Mallomonas spp.	+	-	-	-	-	-	-	-
EUGLENOPHYTA								
Euglena sp.	+	+	-	+	+	-	-	-
Phacus sp.	+	-	-	-	+	-	-	-
Trachelomonas sp.	+	+	-	-	-	-	-	-
RHODOPHYTA								
Batrachospermum vagum (Roth.) C.A. Agardh.	-	-	-	-	-	+	-	-
BACILLARIOPHYTA								
Achnanthes lanceolata Breb.	+	-	+	-	+	-	+	+
Amphipleura lindheimeri Grun.	-	-	+	+	-	-	-	-
A. pellucida Kutz.	-	-	+	+	+	+	[illegible]	-

Appendix 4. Continued.

Algae	Site 1	2	3	4	5	6	7	8
Cocconeis pediculus Ehr.	-	+	+	+	+	+	+	+
C. placentula Ehr.	+	+	+	+	+	+	+	+
Cyclotella meneghiniana (Ehr.) Kutz.	+	-	-	-	-	-	+	-
Cymbella cistula (Hemp.) Grun.	-	-	-	-	+	-	-	-
C. lanceolata (Ehr.) V.H.	+	-	-	-	-	-	-	-
C. prostrata (Berk.) Cl.	-	-	-	-	-	+	-	-
C. ventricosa Kutz.	+	-	+	-	+	+	+	+
Epithemia argus Kutz.	-	-	-	-	+	+	+	+
E. Sorex Kutz.	-	-	-	-	+	+	+	+
E. turgida Kutz.	-	-	-	-	-	+	-	-
Eunoitia pecinalis v. *minor* (Kutz.) Rabh.	-	-	+	-	-	-	+	+
E. valida Hust.	-	-	-	-	-	-	+	+
Fragilaria capucina Desm.	-	-	+	-	-	-	+	+
F. pinnata Ehr.	+	-	-	-	-	-	+	+
F. vaucheriae (Kutz.) Peters.	-	-	-	+	+	+	-	+
Gomphonema lanceolatum Ehr.	-	-	+	+	-	+	+	+
G. olivaceum (Lyngb.) Kutz.	-	-	-	-	+	+	-	-
G. parvulum (Kutz.) Grun.	-	-	+	-	-	-	-	-
Gyrosigma acuminatum (Kutz.) Rabh.	-	-	-	-	+	-	+	+
Hantzschia amphioxys (Ehr.) Grun.	-	-	-	-	-	-	+	+
Meridion circulare Agardh.	-	-	-	+	-	-	-	-
Navicula cryptocephala Kutz.	+	-	+	+	+	+	+	+
N. cuspidata Kutz.	-	-	-	-	-	+	-	-
N. pupula Kutz.	+	-	-	-	-	-	-	-
N. radiosa Kutz.	+	-	+	+	+	+	+	+
Neidium affine (Ehr.) Cl.	-	-	+	-	-	-	-	-
N. affine v. *amphirhynchus* (Ehr.) Cl.	+	-	-	-	-	-	-	-

Appendix 4. Concluded.

Algae	Site 1	2	3	4	5	6	7	8
Nitzschia acuta Hantzsch	-	-	+	-	-	-	-	-
N. dissipata (Kutz.) Grun.	-	-	+	-	-	-	-	-
N. fonticola Grun.	+	-	-	-	-	-	-	-
N. palea (Kutz.) W. Sm.	+	-	+	-	+	+	+	+
N. recta Hantzsch.	+	-	+	+	-	-	+	-
N. sublincaris Hust.	-	-	+	-	-	-	-	-
Pinnularia gibba Ehr.	+	-	-	-	-	-	+	-
P. molaris Grun.	+	-	-	-	-	-	+	-
P. viridis v. *sudetica* (Hilse) Hust.	-	-	-	-	+	-	-	-
Rhopalodia gibba (Ehr.) O. Mull.	+	-	+	-	-	+	+	+
Stauroneis anceps Ehr.	+	-	-	-	-	-	-	-
S. phoenicentron Ehr	+	-	-	-	+	-	-	-
Surirella angustata Kutz.	+	-	+	+	+	+	-	-
S. ovalis Breb.	-	-	-	-	+	-	-	-
Synedra ulna (Nitzsch.) Ehr.	-	-	+	+	-	+	+	+
Tabellaria flocculosa (Roth.) Kutz.	+	-	-	-	-	-	-	-

Appendix 5. The algae found at each site in the Ells River (+ present; - absent).

Algae	Site					
	1	2	3	4	5	6
CYANOPHYTA						
Calothrix braunii	+	-	-	+	-	-
Lyngbya aerugineo-caerula (Kutz.) Gomont	+	+	-	+	-	-
Nostoc spp.	+	-	-	-	-	-
CHLOROPHYTA						
Chlamydomonas sp.	+	+	-	-	-	+
Chlorella vulgaris Beyer.	+	+	-	-	-	-
Cladophora glomerata (L.) Kutz.	+	+	-	-	-	-
Cosmarium spp.	+	-	-	-	-	-
Microspora pachyderma (Wille) Lager.	+	-	-	-	-	-
Microspora sp.	+	-	-	-	-	-
Stigeoclonium sp.	+	-	-	-	-	-
CRYPTOPHYTA						
Cryptomonas ovata Ehr.	-	+	+	-	-	-
CHRYSOPHYTA						
Chromulina spp.	+	-	-	-	-	-
EUGLENOPHYTA						
Phacus sp.	+	-	-	-	-	-
Trachelomanos sp.	+	-	-	-	-	-
BACILLARIOPHYTA						
Achnanthes lanceolata Breb.	+	-	-	-	+	-
A. minutissima Kutz.	-	-	-	-	-	-
Amphipleura lindheimeri Grun.	-	-	-	+	-	-
Asterionella formosa Hass.	+	-	-	-	-	-

Appendix 5. Continued.

Algae	Site 1	2	3	4	5	6
Cocconeis pediculus Ehr.	+	-	+	+	-	-
C. placentula Ehr.	+	+	+	-	+	+
Cyclotella comuta (Ehr.) Kutz.	+	+	+	+	-	-
C. kutzingiana Thwaites	-	-	+	-	-	-
C. meneghiniana Kutz.	+	+	+	-	-	+
Cymatopleura solea (Breb.) W. Sm.	+	-		-	-	-
Cymbella prostrata (Berk.) A.	+	-	-	+	-	-
C. sinuata Greg.	+	+	+	+	+	-
C. ventricosa Kutz.	+	+	+	+	+	-
Diatoma elongatum Agardh.	-	+	-	+	+	-
D. vulgare Bory	+	-	-	-	-	-
D. vulgare v. *grandis* (Sm.) Grun.	+	+	+	+	+	+
Epithemia argus Kutz.	+	-	-	-	-	-
E. sorex Kutz.	+	-	-	+	-	-
Fragilaria capucina Desm.	-	+	-	-	-	-
F. construens (Ehr.) Grun.	+	+	-	+	-	-
F. construens v. *binodis* (Ehr.) Grun.	+	-	-	-	-	-
F. crotonensis Kitton.	-	-	-	+	-	-
F. pinnata Ehr.	-	+	+	+	+	-
V. vaucheriae (Kutz.) Peters.	+	-	+	-	-	+
Frustulia rhomboides v. *amphilpleuroides* Grun.	+	-	-	-	-	-
Gomphonema abbreviatum (Ag.) Kutz.	+	-	-	-	-	-
G. lanceolatum Ehr.	+	+	+	+	-	-
G. olivacium (Lyngb.) Kutz.	+	+	+	+	-	+
Gryrosigma acuminatum (Kutz.) Rabh.	-	-		-	-	-
Melosira varians C.A. Ag.	-	-	-	+	-	-
Navicula cryptocephal Kutz.	-	+	+	+	+	+
N. graciloides A. Mayer	-	-	-	+	+	+

Appendix 5. Concluded.

Algae	Site 1	2	3	4	5	6
N. minima v. *atomoides* (Grun.) Cl.	-	-	-	-	+	-
Nitzschia dissipata (Kutz.) Grun.	+	+	+	+	+	+
N. fonticola Grun.	+	+	+	-	-	-
N. palea (Kutz.) W. Sm.	-	+	+	+	-	+
N. recta Hantzach.	+	-	+	-	+	-
Pinnularia molaris Grun.	-	-	+	-	-	-
Rhoicosphemia curvata (Kutz.) Grun.	-	-	-	+	-	-
Rhopalodia gibberula (Ehr.) O. Mull.	-	-	-	-	+	-
Stephanodiscus astraea (Ehr.) Grun.	-	+	-	-	-	-
Surirella angustata Kutz.	-	-	-	-	+	-
Synedra ulna (Nitzsch.) Ehr.	-	+	-	+	+	-

Appendix 6. Summary of factors potentially influencing the growth of the major algal groups.

Algal Groups	Factors
DIATOMS	
Muskeg River	
Entire period	Irradiance.
Open water 1978	Current velocity.
Open water 1979	Irradiance; NO_3-N; Temperature.
Steepbank River	
Entire period	Irradiance; Temperature; Current velocity.
Open water 1978	
Open water 1979	Temperature; Current velocity; Discharge; NO_3-N.
Hangingstone River	
Entire period	SiO_2; Discharge; Current velocity.
Open water 1978	SiO_2
Open water 1979	Temperature; Current velocity; Discharge; Ca; Na.
MacKay River	
Entire period	Irradiance; NO_3-N.
Open water 1978	Discharge; Current velocity; SiO_2; Irradiance.
Open water 1979	Irradiance; PO_4-P; SiO_2.
Ells River	
Entire period	Na; Ca; Irradiance; PO_4-P.
Open water 1978	Temperature; Irradiance; Current velocity; Discharge.
Open water 1979	Ca; Temperature; Po_4-P; Discharge; Current velocity; NO_3-N.

Appendix 6. Continued.

Algal Groups	Factors
CHOROPHYTA	
Muskeg River	
Entire period	Temperature.
Open water 1978	Calcium.
Open water 1979	Irradiance; NO_3-N; Temperature; Discharge; SiO_2.
Steepbank River	
Entire period	NO_3-N; Temperature; SiO_2.
Open water 1978	SiO_2; Current velocity; Discharge.
Open water 1979	Temperature; NO_3-N; PO_4-P; SiO_2.
Hangingstone River	
Entire period	Temperature; Fe; SiO_2; Irradiance; Current velocity; Discharge.
Open water 1978	Current velocity; Discharge.
Open water 1979	SiO_2; Na; NO_3-N; PO_4-P; Current velocity; Discharge.
MacKay River	
Entire period	Irradiance; Current velocity; Discharge; Temperature; SiO_2; NO_3-N.
Open water 1978	Current velocity; Discharge; Fe.
Open water 1979	Current velocity; Discharge; Temperature; PO_4-P; Na.
Ells River	
Entire period	PO_4-P; Na.
Open water 1978	Discharge; Current velocity.
Open water 1979	Temperature; PO_4-P; Irradiance; Na; Ca.

Appendix 6. Continued.

Algal Groups	Factors
CYANOPHYTA	
Muskeg River	
Entire period	SiO_2; Discharge.
Open water 1978	Current velocity; Discharge.
Open water 1979	NO_3-N; Irradiance; Temperature; SiO_2; Discharge.
Steepbank River	
Entire period	Irradiance.
Open water 1978	Current velocity; Discharge.
Open water 1979	Current velocity; Discharge; Temperature; Na; Ca; SiO_2; PO_4-P; NO_3-N.
Hangingstone River	
Entire period	SiO_2; K; Discharge; Current velocity; NO_3-N.
Open water 1978	Current velocity; Discharge; NO_3-N.
Open water 1979	SiO_2; PO_4-P; Na; Discharge; Current velocity.
MacKay River	
Entire period	Irradiance; SiO_2; Temperature; PO_4-P.
Open water 1978	Discharge.
Open water 1979	Irradiance.
Ells River	
Entire period	NO_3-N; Irradiance; PO_4-P.
Open water 1978	-
Open water 1979	Ca; Temperature; Na.

Appendix 6. Concluded.

Algal Groups	Factors
RHODOPHYTA	
Muskeg River	
Entire period	SiO_2; Temperature; Ca; Mg; Current velocity; Mn.
Open water 1978	Irradiance.
Open water 1979	Irradiance; NO_3-N; PO_4-P.
Steepbank River	
Entire period	Irradiance; Temperature; SiO_2.
Open water 1978	NO_3-N; Current velocity; Discharge.
Open water 1979	Irradiance; NO_3-N.

Appendix 6b. Summary of factors potentially influencing epilithic algal standing crops.

Study Period	Factors
Muskeg River	
Entire period	Temperature.
Open water 1978	Current velocity.
Open water 1979	Temperature.
Steepbank River	
Entire period	Current velocity; Discharge.
Open water 1978	SiO_2; NO_3-N; Irradiance; Current velocity; Discharge.
Open water 1979	Current velocity; Discharge; Temperature; Irradiance; Na; Ca; SiO_2; NO_3-N; PO_4-P.
Hangingstone River	
Entire period	Current velocity; Discharge; Temperature.
Open water 1978	NO_3-N; Irradiance; SiO_2; Fe; Current velocity; Discharge.
Open water 1979	Current velocity; Discharge; Temperature; Irradiance; Ca; Na; SiO_2; NO_3-N; PO_4-P.
MacKay River	
Entire period	Current velocity; Discharge.
Open water 1978	Irradiance; PO_4-P; NO_3-N; Discharge; Temperature; Fe; SiO_2; Mn; Current velocity
Open water 1979	Current velocity; Fe; Discharge; NO_3-N; Na.
Ells River	
Entire period	SiO_2; NO_3-N; Ca; Na; Irradiance.
Open water 1978	Temperature; Irradiance; Mn; Current velocity; Discharge.
Open water 1979	Current velocity; Discharge; SiO_2; Mn.

Appendix 7. Summary of factors potentially influencing epilithic algal primary productivity.

Muskeg River	
Entire period	Standing crop; Ca; SiO_2; Mg.
Open water 1978	Standing crop.
Open water 1979	Mn; K; SiO_2; Mg; Standing crop; Temperature; PO_4-P; Na; Cl.
Steepbank River	
Entire period	Cl; Mg; K; NO_3-N; Irradiance.
Open water 1978	-
Open water 1979	Standing crop; Irradiance; Temperature; NO_3-N.
Hangingstone River	
Entire period	NO_3-N; Ca; Mg; Cl; K; Temperature.
Open water 1978	Standing crop.
Open water 1979	Standing crop.
MacKay River	
Entire period	NO_3-N; Irradiance; Standing crop; SiO_2; Mg.
Open water 1978	Irradiance; PO_4-P; NO_3-N; Standing crop; Fe; Mg; Ca; Temperature; SiO_2; Mn.
Open water 1979	Temperature; Irradiance.
Ells River	
Entire period	PO_4-P; Standing crop; Ca; Temperature.
Open water 1978	Fe; SiO_2; Mn.
Open water 1979	Temperature; Irradiance; Standing crop.

Appendix 8. Correlations between epilithic algal standing crop and primary productivity for the entire study period and for the open water periods of 1978 and 1979.

River		Open Water Period	
	Entire Study Period	1978	1978
Muskeg	r = 0.356 p 0.05	r = 0.536 p 0.05	r = 0.678 p 0.10
Steepbank	N.S.	N.S.	r = 0.989 p 0.005
Hangingstone	N.S.	r = 0.668 p 0.10	r = 0.921 p 0.10
MacKay	r = 0.310 p 0.25	r = 0.776 p 0.05	N.S.
Ells	r = 0.519 p -0.10	N.S.	r = 0.603 p 0.25

Appendix 9. Correlations between epilithic algal nitrogen fixation and nitrate nitrogen, chlorophyll a, numbers of Cyanophyceae and temperature.

River	Nitrate Nitrogen	Cyanophycean Numbers	Temperature	Chlorophyll a
Muskeg				
r	-0.304	0.274	-0.202	-0.410
	p .05	p .08	p .18	p .01
multiple r	0.518	0.522	0.411	0.410
Steepbank				
r	-0.258	-0.116	0.865	0.460
	p .18	p .34	p .01	p .05
multiple r	0.872	0.879	0.855	0.879
Hangingstone				
r	-0.397	-0.279	0.890	0.302
	p .08	p .20	p .01	p .15
multiple r	0.905	--	0.873	0.933
MacKay				
r	-0.161	0.273	0.438	0.089
	p .27	p .16	p .05	p .38
multiple r	0.373	--	0.369	0.250
Ells				
r	-0.064	-0.496	0.796	0.429
	p .41	p .04	p .01	p .07
multiple r	0.815		0.747	0.813
All Rivers	-0.282	0.240	0.398	0.036
Date Combined	p .01	p .01	p .01	p .37
multiple r	0.418	0.352	0.464	0.471

Appendix 10a. The mean and range for various physical and chemical factors for the five rivers.

		Rivers				
	Units	Muskeg	Steepbank	Hangingstone	MacKay	Ells
Temperature	^{o}C	0.4 - 21.2 $\bar{x}$ = 10.8	0 - 20.1 $\bar{x}$ = 7.72	0 - 19.0 $\bar{x}$ = 7.65	0 - 0.051 $\bar{x}$ = 9.60	0 - 19.3 $\bar{x}$ = 7.38
Conductance	units	120 - 400 $\bar{x}$ = 233.6	75 - 420 $\bar{x}$ = 210.0	90 - 425 $\bar{x}$ = 237.4	134 - 580 $\bar{x}$ = 206.8	90 - 125 $\bar{x}$ = 109.4
Calcium	$mg.L^{-1}$	11.0 -44.8 $\bar{x}$ = 21.9	8.0 - 43.0 $\bar{x}$ = 19.1	4.5 - 33.8 $\bar{x}$ = 18.2	10.0 - 49.5 $\bar{x}$ = 22.9	7.8 - 16.9 $\bar{x}$ = 12.6
Sodium	$mg.L^{-1}$	5.6 - 33.2 $\bar{x}$ = 18.1	3.9 - 48.7 $\bar{x}$ = 20.0	7.4 - 56.3 $\bar{x}$ = 27.3	7.9 - 57.5 $\bar{x}$ = 33.1	3.2 - 4.8 $\bar{x}$ = 3.9
Potassium	$mg.L^{-1}$	0.1 - 5.7 $\bar{x}$ = 1.30	0.1 - 2.4 $\bar{x}$ = 0.70	0.1 - 3.6 $\bar{x}$ = 1.47	0.1 - 3.2 $\bar{x}$ = 1.44	0.1 - 2.4 $\bar{x}$ = 0.89
Magnesium	$mg.L^{-1}$	2.9 - 16.8 $\bar{x}$ = 7.8	1.1 - 16.2 $\bar{x}$ = 7.9	0.81 - 14.1 $\bar{x}$ = 7.1	2.12 - 21.4 $\bar{x}$ = 9.2	1.6 - 4.9 $\bar{x}$ = 3.6
Iron	$mg.L^{-1}$	0.03 - 0.99 $\bar{x}$ = 0.18	0.04 - 0.22 $\bar{x}$ = 0.12	0.05 - 0.48 $\bar{x}$ = 0.16	0.02 - 0.36 $\bar{x}$ = 0.16	0.04 - 0.13 $\bar{x}$ = 0.08
Manganese	$mg.L^{-1}$	0.004- 0.063 $\bar{x}$ = 0.014	0.002 - 0.053 $\bar{x}$ = 0.013	0.004 - 0.095 $\bar{x}$ = 0.021	0.002 - 0.051 $\bar{x}$ = 0.009	0.004 - 0.018 $\bar{x}$ = 0.010
Sulphate	$mg.L^{-1}$	0 - 3.75 $\bar{x}$ = 1.09	0.1 - 14.0 $\bar{x}$ = 6.60	3.5 - 28.3 $\bar{x}$ = 15.7	10.5 - 53.0 $\bar{x}$ = 27.3	4.4 - 9.0 $\bar{x}$ = 6.39

Appendix 10a. Concluded.

		Rivers				
	Units	Muskeg	Steepbank	Hangingstone	MacKay	Ells
Chloride	mg.L^{-1}	0 - 35.6 $\bar{x}$ = 10.3	0 - 8.0 $\bar{x}$ = 1.75	1.0 - 30.0 $\bar{x}$ = 11.5	0 - 20.0 $\bar{x}$ = 7.58	0 $\bar{x}$ = 0
Nitrate-nitrogen	mg.L^{-1}	0.104- 0.298 $\bar{x}$ = 0.196	0.150- 0.345 $\bar{x}$ = 0.224	0.166- 0.425 $\bar{x}$ = 0.237	0.135- 0.515 $\bar{x}$ = 0.290	0.081 - 0.161 $\bar{x}$ = 0.122
Phosphate-phosphorus	mg.L^{-1}	0.006- 0.352 $\bar{x}$ = 0.030	0.013- 0.232 $\bar{x}$ = 0.049	0.006- 0.600 $\bar{x}$ = 0.104	0.008- 0.157 $\bar{x}$ = 0.050	0.012 - 0.285 $\bar{x}$ = 0.069
Dissolved Silica	mg.l^{-1}	0.80 - 9.90 $\bar{x}$ = 5.33	1.20 - 10.65 $\bar{x}$ = 4.54	2.70 - 9.75 $\bar{x}$ = 5.54	0.45 - 9.15 $\bar{x}$ = 3.07	0.32 - 2.20 $\bar{x}$ = 1.17
pH		6.20 - 8.40	6.40 - 8.25	6.50 - 8.50	6.30 - 8.65	6.00 - 9.00
Total Alkalinity	meq.HCO$_3$.L^{-1}	1.9 - 4.26 $\bar{x}$ = 2.48	0.82 - 5.30 $\bar{x}$ - 2.42	0.99 - 3.95 $\bar{x}$ = 2.14	0.99 - 4.98 $\bar{x}$ = 2.52	0.80 - 1.50 $\bar{x}$ = 0.97
Discharge	m^3.s^{-1}	0.48 - 22.4 $\bar{x}$ = 4.78	0.33 - 61.5 $\bar{x}$ = 10.06	0.21 - 19.1 $\bar{x}$ = 4.94	0.5 - 86.1 $\bar{x}$ = 12.25	1.6 - 44.6 $\bar{x}$ = 10.6

Appendix 10b. Relationships between various parameters and discharge

Parameter	Muskeg	Steepbank	Hangingstone	MacKay	Ells
Na	$y=21.9-2.7 \ln x$ $r=-0.368$ p 0.025	$y=30.5-0.01 \ln x$ $r=-0.894$ p 0.005	$y=31.5-4.9 \ln x$ $r=-0.562$ p 0.01	$y=54.3-12.3 \ln x$ $r=-0.834$ p 0.005	$y=4.4-0.3 \ln x$ $r=-0.695$ p 0.005
K	N.S.	N.S.	$y=1.9-0.1 \ln x$ $r=0.351$ p 0.10	N.S.	
Mg	$y=10.1-2.1 \ln x$ $r=-0.674$ p 0.005	$y=12.2-2.0 \ln x$ $r=-0.894$ p 0.005	$y=9.6-2.6 \ln x$ $r=-0.859$ p 0.005	$y=11.6-2.3 \ln x$ $r=-0.631$ p 0.005	$y=4.1-0.05 \ln x$ $r=-0.702$ p 0.005
Ca	$y=26.6-3.9 \ln x$ $r=-0.618$ p -.005	$y=24.6-3.9 \ln x$ $r=-0.657$ p 0.005	$y=22.1-4.2 \ln x$ $r=-0.733$ p 0.005	$y=29.96-4.8 \ln x$ $r=-0.636$ p 0.004	N.S.
Cl^-	N.S.	$y=4.6-1.8 \ln x$ $r=-0.754$ p 0.005	$y=15.9-4.8 \ln x$ $r=-0.836$ p 0.005	$y=13.4-3.9 \ln x$ $r=-0.806$ p 0.005	N.S.
SO_4	N.S.	$y=9.9-2.3 \ln x$ $r=-0.780$ p 0.005	$y=2-.2-4.8 \ln x$ $r=-0.919$ p 0.005	$y=38.4-7.5 \ln x$ $r=-0.845$ p 0.005	N.S.
SiO_2	$y=6.5-0.99 \ln x$ $r=-0.469$ p 0.005	$y=6.0-1.1 \ln x$ $r=-0.536$ p 0.005	$y=6.7-1.1 \ln x$ $r=-0.676$ p 0.005	N.S.	N.S.
PO_4-P	$y=0.02-0.002 \ln x$ $r=-0.295$ p 0.05	$y=0.09-0.03 \ln x$ $r=-0.625$ p 0.005	N.S.	N.S.	N.S.
NO_3-N	N.S.	$y=0.2+0.19 \ln x$ $r=0.431$ p 0.05	N.S.	N.S.	N.S.

**N.S.=not significant

Appendix 11. Correlations between epilithic algal standing crop and potentially limiting nutrients for the entire study period and for the open water periods of 1978 and 1979.

Nutrient	Muskeg	Steepbank	Hangingstone	MacKay	Ells
			Entire Study Period		
SiO_2	N.S.[a]	r = 0.385 p 0.10	N.S.	N.S.	r = -0.420 p 0.10
NO_3-N	N.S.	N.S.	N.S.	N.S.	N.S.
PO_4-P	N.S.	N.S.	N.S.	N.S.	r = -0.365 p 0.10
Mn	N.S.	r = 0.747 p 0.005	r = 0.687 p 0.005	N.S.	r = 0.447 p 0.05
Ca	N.S.	r = 0.371 p 0.10	r = 0.412 p 0.05	N.S.	r = -0.442 p 0.05
Na	N.S.	N.S.	N.S.	N.S.	r = -0.357 p 0.10
			Open Water Period (1978)		
SiO_2	N.S.	r = -0.726 p 0.10	r = -0.590 p 0.10	r = -0.854 p 0.01	N.S.
NO_3-N	N.S.	r = -0.675 p 0.10	r = -0.679 p 0.05	r = 0.918 p 0.01	N.S.
PO_4-P	N.S.	N.S.	N.S.	r = -0.932 p 0.01	N.S.
Fe	N.S.	N.S.	r = -0.591 p 0.10	r = -0.875 p 0.01	N.S.
Mn	N.S.	N.S.	N.S.	r = -0.774 p 0.05	r = -0.610 p 0.10

Appendix 11. Concluded.

Nutrient	Open Water Period (1979)				
	Muskeg	Steepbank	Hangingstone	MacKay	Ells
SiO_2	N.S.	r = 7.17 p 0.10	r = 0.621 p 0.10	N.S.	r = 0.594 p 0.25
NO_3-N	r= -.404 p -0.25	N.S.	r = 0.479 p 0.25	r = -0.605 p 0.25	N.S.
PO_4-P	N.S.	r = 0.385 p 0.25	r = 0.464 p 0.25	N.S.	N.S.
Fe	r=-0.427 p 0.25	r = 0.406 p 0.25	N.S.	r = -0.679 p 0.10	N.S.
Ca	N.S.	N.S.	r = 0.828 p 0.05	N.S.	N.S.
Na	N.S.	N.S.	r = 0.538 p 0.25	r = 0.862 p 0.05	N.S.
Mn	N.S.	N.S.	N.S.	N.S.	r = 0.627 p 0.25

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[a] N.S. = Not significant.

Appendix 11b. Correlations between epilithic algal standing crop and physical factors for the entire study period and for the open water periods of 1978 and 1979.

Physical Factors	Muskeg	Steepbank	Hangingstone	MacKay	Ells
			Entire Study Period		
Temperature	r=-0.265 p 0.10	N.S.	r = -0.191 p 0.25	N.S.	N.S.
Irradiance	N.S.	N.S.	N.S.	N.S.	r = -0.231 p 0.25
Current Velocity	r=-0.146 p 0.25	r=-0.236 p 0.25	r = -0.231 p 0.25	r = -0.287 p 0.25	N.S.
Discharge	r=-0.168 p 0.25	r=-0.202 p 0.25	r = -0.217 p 0.25	r = -306	N.S. p 0.10
			Open Water Period (1978)		
Temperature	N.S.	N.S.	N.S.	r = 0.893 p 0.01	r = -0.746 p 0.05
Irradiance	N.S.	r=0.637 p 0.10	r = 0.637 p 0.05	r = 0.958 p 0.01	r = -0.695 p 0.10
Current Velocity	r=-0.385 p 0.10	r=-0.629 p 0.10	r = -0.447 p 0.25	r = -0.720 p 0.05	r = 0.416 p 0.25
Discharge	N.S.	r=-0.596 p 0.25	r = -0.413 p 0.25	r = -0.909 p 0.01	r = -.354 p 0.25
			Open Water Period (1979)		
Temperature	r=-0.625 p 0.10	N.S.	r = -0.421 p 0.25	r = -0.592 p 0.25	N.S.
Irradiance	r=-0.516 p 0.25	N.S.	r = -0.448 p 0.25	N.S.	N.S.
Current Velocity	N.S.	r = -0.651 p 0.10	r = -0.664 p 0.10	r = -0.764 p 0.10	r = 0.671 p 0.25
Discharge	N.S.	r = -0.628 p 0.10	r = -0.517 p 0.25	r = -0.635 p 0.25	r = 0.639 p 0.25